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# **THIRD TRI-SERVICE ENVIRONMENTAL TECHNOLOGY WORKSHOP**

**"Environmental Technology: Preserving the Balance"  
18-20 August 1998 - San Diego, California**

## **Proceedings**

*This is a complete agenda of the workshop proceedings.  
Articles included in this document are highlighted.  
For more information contact the presenters of the individual articles.  
Presenters are not necessarily the primary authors.*

**TUESDAY, 18 AUGUST 1998**

### **INFORMATION SYSTEMS I**

Chair: Mr. Warren Meekins

Defense Environmental Security Corporate Information Management Program  
Office

#### **Integration of the Army's Environmental RDT&E Program and Commercial Technologies into the "User" Community's Operations**

Mr. John Murphy and Ms. Julie Van Deuren, Platinum International, Inc.,  
Alexandria, VA

#### **New Air Force Fuels Handbook - IS1-2**

Mr. Sam A. Taffinder, Air Force Center for Environmental Excellence,  
Brooks Air Force Base, TX

#### **Introducing USACE's In Situ Air Sparging Engineer Manual - IS1-3**

Dr. Ralph Baker, ENSR Consulting and Engineering, Acton, MA

#### **Consensus Building at Naval Facilities Using GIS - IS1-4**

Mr. Michael R. Wild, NewFields, Inc., Atlanta, GA

#### **Integrating Geographical Information on the Web - IS1-5**

Mr. Joe Jahnke, Rust Environmental and Infrastructure, Warner Robins, GA

#### **Applications of Graphically-Based Management Systems for Contaminated Groundwater - IS1-6**

Mr. Steven G. Light, U.S. Army Engineering and Support Center,  
Huntsville, AL

### **REMEDIATION I**

Chair: Ms. Carmen LeBron

Naval Facilities Engineering Service Center

#### **Barometrically Driven Bioventing in Stratified Soils and Shallow Groundwater Conditions - R1-1**

Mr. Michael Phelps, Parsons Engineering Science, Inc., Oakland, CA

*199-10-1619*

**Air Sparging for Remediation of Contaminated Groundwater - R1-2**  
Ms. Andrea Leeson, Battelle, Columbus, OH

**The Use of In Situ Groundwater Flow Sensors to Evaluate Air Sparging - R1-3**  
Mr. David A. Wardwell, Mission Research Corporation (MRC),  
Albuquerque, NM

**The Trials and Tribulations of Multi-Agency/Joint Services Installation Restoration Program Partnering - R1-4**  
Ms. V. Ramona Wilson, Air Force Eastern Regional Environmental Office,  
Atlanta, GA

**Innovative Techniques to Emplace Zero Valent Iron - R1-5**  
Major Edward G. Marchand, Air Force Center for Environmental  
Excellence, Brooks Air Force Base, TX

**Evaluating the Performance of a Permeable Reactive Barrier, Moffett Field, Mountain View, California - R1-6**  
Mr. Charles Reeter, Naval Facilities Engineering Service Center, Port  
Hueneme, CA

#### **CHARACTERIZATION**

Chair: Mr. Robert Kratzke  
Naval Facilities Engineering Service Center

**Site Characterization for Explosives Contamination at Military Firing Ranges - CH-1**  
Dr. Sonia Thiboutot, Canadian Defence Research, Val-Belair, Quebec,  
CANADA

**Advanced Sediment Characterization Using Biogeochemical Fingerprinting - CH-2**  
Mr. Sabine E. Apitz, Remediation Research Laboratory, San Diego, CA

**Field Portable X-Ray Fluorescence (FPXRF) for the On Site Measurement of Metals in Marine Sediments: Streamlined Site Mapping and Assessment - CH-3**  
Ms. Victoria Kirtay, Remediation Research Laboratory, San Diego, CA

**Low-Flow Groundwater Sampling Systems Technology Applications**  
Ms. Lindy K. Austin, Rust Environment & Infrastructure, San Jose, CA

**High Resolution 3D Geophysical Surveys (Seismic Reflection and Electromagnetic Resistivity) for Locating Subsurface DNAPL - CH-5**  
Mr. Nate Sinclair, Naval Facilities Engineering Service Center, Port  
Hueneme, CA

**Some Techniques for Evaluating the Exchange of Contaminants at the Sediment-Water Interface - CH-6**  
Maj. D. Bart Chadwick, SPAWAR Systems Center - San Diego, San Diego,  
CA

**WEDNESDAY, 19 AUGUST 1998**

**POLLUTION PREVENTION I**  
Chair: Major Edward Marchand

Air Force Center for Environmental Excellence

**Presentation**

Ms. Nancy A. Carper, HQ Air Force Center for Environmental Excellence,  
Brooks AFB, TX

**Transferring the FLASHJET® Coatings Removal Technology to DoD  
Facilities**

Mr. Rick O'Donnell, U.S. Army Environmental Center, Aberdeen Proving  
Ground, MD

**Alternative Fuel Vehicles at McClellan Air Force Base - PP1-3**

Mr. Philip H. Mook, McClellan Air Force Base, McClellan Air Force Base,  
CA

**DoD Pesticide Reduction Policies and Integrated Weed Management  
Practices at Army Installations - PP1-4**

Dr. Steven R. Bennett, U.S. Army Environmental Center, Aberdeen Proving  
Ground, MD

**Evaluation of Retrofitting Existing Oil/Water Separators - PP1-5**

Mr. Dennis A. Teefy, U.S. Army Environmental Center, Aberdeen Proving  
Ground, MD

**What If We Could Purify and Reuse Waste Hydraulic Fluid? - PP1-6**

Mr. Edward B. Seaman, TRW, Tyndall Air Force Base, FL

**REMEDIATION II**

Chair: Dr. Kurt Riegel

Office of the Assistant Secretary of the Navy for Installations and Environment

**Numerical Modeling of the Natural Attenuation of Explosives - R2-1**

Mr. Christian J. McGrath, USAE Waterways Experiment Station,  
Vicksburg, MS

**Phytoremediation of Explosives Contaminated Groundwater Using  
Constructed Wetlands Technology: Efficacy and Economics - R2-2**

Mr. Richard A. Almond, Tennessee Valley Authority, Muscle Shoals, AL;  
Ms. Darlene F. Bader, U.S. Army Environmental Center, Aberdeen Proving  
Ground, MD

**Natural Attenuation of Chlorinated Solvents at a Former Landfill, Naval Air  
Station North Island - R2-3**

Mr. John A. Jackson, Parsons Engineering Science, Inc., Pasadena, CA

**Combining Natural Attenuation and Site-Specific Remediation Goals for Site  
Closure - R2-4**

Mr. Douglas C. Downey, Parsons Engineering Science, Inc., Denver, CO

**Use of Innovative Site Characterization Technologies for Environmental  
Remediation by the U.S. Army Corps of Engineers**

Ms. Kira Lynch, U.S. Army Corps of Engineers, Seattle, WA

**The Air Force Biochlor Natural Attenuation Model and Database for  
Chlorinated Solvents - R2-6**

Mr. Charles J. Newell, Groundwater Services, Inc., Houston, TX, et. al.



## **RANGE RULE**

Chair: Ms. Karen Heckelman  
U.S. Army Environmental Center

### **Range Rule Overview and Objective**

Ms. Karen Heckelman, U.S. Army Environmental Center, Aberdeen Proving Ground, MD

### **Range Rule Development and Status**

Ms. Karen Heckelman, U.S. Army Environmental Center, Aberdeen Proving Ground, MD

### **Munitions Rule Overview and Update**

Ms. Karen Heckelman, U.S. Army Environmental Center, Aberdeen Proving Ground, MD

### **Range Rule Risk Method Overview**

Mr. Scott Hill, U.S. Army Environmental Center, Aberdeen Proving Ground, MD

### **Risk Management Strategy Development**

Mr. Scott Hill, U.S. Army Environmental Center, Aberdeen Proving Ground, MD

### **Range Rule Technology Needs**

Mr. Scott Hill, U.S. Army Environmental Center, Aberdeen Proving Ground, MD

## **INFORMATION SYSTEMS II**

Chair: TBA

### **Remediation Technologies Screening Matrix and Reference Guide, Version III - IS2-1**

Mr. Dennis Teefy, U.S. Army Environmental Center, Aberdeen Proving Ground, MD

### **Subsurface Hydrogen Delivery for the In-Situ Bioremediation of Chlorinated Solvents - IS2-2**

Mr. Charles J. Newell, Groundwater Services, Incorporated (GSI), Houston, TX

### **Joint Service Pollution Prevention Technical Library - IS2-3**

Mr. Larry Hill, Naval Facilities Engineering Service Center, Honolulu, HI

### **Managing Environmental Information at Military Installations - IS2-4**

Mr. Richard Machanoff, HAZWRAP/DOE, Oak Ridge, TN

### **U.S. Army Hazardous Substance Management System (HSMS) Implementation - IS2-5**

Mr. Tom Guinivan, U.S. Army Environmental Center, Aberdeen Proving Ground, MD

### **Lead Based Paint Hazard Control - IS2-6**

Dr. Ashok Kumar, U.S. Army Construction Engineering Research Laboratories, Champaign, IL

## **REMEDIATION III**

Chair: Mr. Erik Hangeland  
U.S. Army Environmental Center

**Field Demonstration and Laboratory Testing of Six Commercially Available Bioremediation Technologies at the Joliet Army Ammunition Plant - R3-1**

Mr. Philip Rappa, III, Plexus Scientific Corporation, Silver Spring, MD

**Field Demonstration of Multiple Bioslurry Treatment Technologies for Explosives-Contaminated Soils**

Mr. Eric Hangeland, U.S. Army Environmental Center, Aberdeen Proving Ground, MD

Authors: Mr. Mark L. Hampton, U.S. Army Environmental Center, and Dr. John F. Manning, Argonne National Laboratory, Argonne, IL)

**Automated Soil-Gas Monitoring During Biopile Operations - R3-3**

Mr. Albert J. Pollack, Battelle Memorial Institute, Columbus, OH

**Low-Cost Disposable Hot Gas Decontamination System for Explosive-Contaminated Equipment and Facilities - R3-4**

Mr. Robert Ferguson, Grace Bioremediation Technologies, Yardley, PA

Author: Mr. William J. Kelso, Parsons Engineering Science, Denver, CO

**Characterization and Remediation of a DNAPL Contaminated Aquifer at OU2, Hill AFB, Utah - R3-5**

Ms. Jacqueline Avvakoumides, Duke Engineering and Services, Austin, TX

**Surfactant-Enhanced DNAPL Removal - R3-6**

Ms. S. Laura Yeh, Naval Facilities Engineering Service Center, Port Hueneme, CA

**COMPLIANCE**

Chair: Mr. Robert Scola, Director  
Industrial Ecology Center, U.S. Army Armament Research, Development, and Engineering Center

**Natural Landfill Covers - CO-1**

Dr. Victor L. Hauser, Mitretek Systems, San Antonio, TX

**Infiltration Control Landfill Cover Designs - CO-2**

Mr. Bryan Harre, Naval Facilities Engineering Service Center, Port Hueneme, CA

**NitRem Technology Successful Treats DoD Waste - CO-3**

Mr. Robert E. Goldberg, U.S. Army TACOM/ARDEC, Picatinny Arsenal, NJ

**Low Range Differential Pressure (LRDP) Leak Detection System for Bulk USTS - CO-4**

Mr. William Major, Naval Facilities Engineering Service Center, Port Hueneme, CA

**Cost-Effective Sampling (CES) of Ground Water Monitoring Wells - CO-5**

Ms. Maureen Ridley, Lawrence Livermore National Laboratory, Livermore, CA

**Pink Water Treatment Technology Evaluations - CO-6**

Dr. Mahmood Qazi, Concurrent Technologies Corporation, Johnstown, PA

**THURSDAY, 20 AUGUST 1998**

**POLLUTION PREVENTION II**

Chair: Mr. Les Keffer  
Headquarters, Air Force

**Continuous Processing: An Environmentally Friendly Manufacturing Technology for Energetic Materials - PP2-1**

Mrs. Constance M. Murphy, Naval Surface Warfare Center, Indian Head, MD

**Biodegradation of Ammonium Perchlorate - PP2-2**

Mr. James A. Hurley, Air Force Research Laboratory, Tyndall Air Force Base, FL

**Landfill Closure Optimization - PP2-3**

**Mr. Eric Munro, IT Corporation, Martinez, CA**

**Should You? Can You? Replace the CFC's in Your Systems - PP2-4**

Mr. Colin Munday, InterCool Energy Corporation, Latham, NY

**Hydraulic Oil Recycling - PP2-5**

Mr. Neal C. Werner, Pall Aeropower Corporation, Clearwater, FL

**REMEDIATION IV**

Chair: Mr. Kevin Doxey  
Office of the Deputy Under Secretary of Defense (Environmental Security)

**Full-Scale Implementation of Bioslurping for Free-Product Recovery - R4-1**

Mr. Stephen Rosansky, Battelle Memorial Institute, Columbus, OH

**Field Demonstration of In-Well Aeration Technology (a.k.a. Groundwater Circulation Wells) - R4-2**

Mr. James R. Gonzales, Air Force Center for Environmental Excellence, Brooks Air Force Base, TX

**Treatment of Solvent Contaminated Soil and Groundwater Using Six-Phase Heating Combined with Soil Vapor Extraction - R4-3**

Mr. Bernard Gagnon, USACE, Alaska District, Anchorage, AK

**Volatile Organic Compound (VOC) Offgas Treatment Technology Demonstration and Comparison - R4-4**

Mr. Richard G. Mach, Naval Facilities Engineering Service Center, San Diego, CA

**Application of In Situ Thermal Desorption to Destroy PCBs in Soil**

Mr. Denis Conley, Shell-TerraTherm Environmental Services, Inc, The Woodlands, TX

*Contact us about this document.  
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# Attendees

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	R	S	T	V	W	Y	Z
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# **Barometrically Driven Bioventing in Stratified Soils and Shallow Groundwater Conditions**

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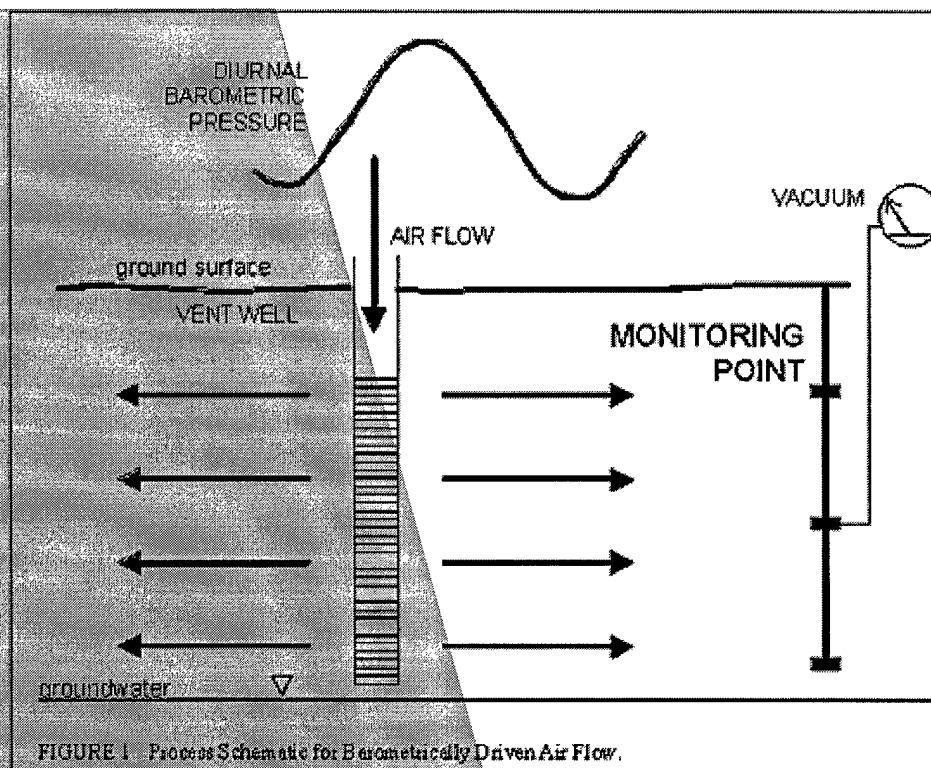
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## **Introduction/Technology Description**

Bioventing is a proven, cost-effective remedial technology which has been applied at numerous Department of Defense installations in the United States and worldwide (Miller *et al.*, 1993; Leeson and Hinchee, 1997). As conventionally applied, bioventing requires a blower to either inject or extract air. However, it has been observed at several sites that natural movement of gases into and out of the vadose zone, due to barometric pressure fluctuations with time, can also provide oxygen for biodegradation. A passive bioventing system, which utilizes and promotes this natural movement of gases and does not require a blower, would have a significantly simpler design, cost less to install and operate, and could be used at remote sites where power is either unavailable or cost-prohibitive to install.

Field tests have shown that daily changes in barometric pressure cause open vadose wells to inhale and exhale air (sometimes termed "barometric pumping" or "breathing") (Pirkle *et al.*, 1992; Rossabi *et al.*, 1993; Foor *et al.*, 1995; Zimmerman *et al.*, 1997). This phenomenon is illustrated on Figure 1. During times of increasing barometric pressure, a negative pressure gradient is potentially developed between the atmosphere and the subsurface, which is measurable as a vacuum at subsurface monitoring points. Air flow can occur into the subsurface if vent wells or monitoring wells are installed and appropriately screened at depths where significant gradients are developed. The reverse effect occurs during times of decreasing barometric pressure (i.e., positive pressure gradients are developed and air flows out of the well). The magnitude of the pressure gradient (and, therefore, the magnitude of the air flow rate) is primarily a function of the magnitude and rate of barometric pressure change, depth, soil air permeability, and soil porosity.



Previous passive bioventing demonstrations have been primarily performed at sites with deep vadose zones (groundwater table at 100 feet or more below ground surface [bgs]), where it is intuitive that pressure gradients with depth could be achieved. At these sites, natural daily barometric pressure changes induced air flows of up to 15 cubic feet per minute (cfm) into vadose zone wells. However, theoretically passive bioventing should also work at sites with shallower groundwater or a stratified lithology, where pressure gradients would exist due to significant vertical variation in soil air permeability and/or porosity. At many sites, natural geologic stratification can severely limit vertical air flow and relatively large radii of influence have been achieved at such sites during conventional bioventing.

## Demonstration Site Description

A field demonstration of passive bioventing is currently being conducted through an interagency partnership at a site with a stratified lithology and a groundwater depth of approximately 60 feet bgs. The site is located at Castle Airport (formerly Castle Air Force Base) in California's Central Valley. The demonstration site is a former Petroleum, Oils, and Lubricants fuel farm built in the 1940's and was the bulk fuel storage and distribution facility for the base. Extensive remedial investigations identified soil and groundwater contamination, primarily petroleum hydrocarbons, as a result of surface spills, leaking underground storage tanks, and fuel distribution lines.

A generalized cross-section is shown on Figure 2. The shallow subsurface stratigraphy is characterized by alluvial deposits consisting of interbedded sequences of clays, silts, and sands. The subsurface in the upper 15 feet is comprised predominantly of silty sand, overlying a laterally continuous clay/silt layer between approximately 15 and 25 feet bgs. Between 25 and 35 feet bgs, sand with little to no fines predominates. This sand is then underlain by another continuous clay/silt layer approximately 5 to 10 feet in thickness. Below this

second clay/silt layer, sand extends to the groundwater table. Currently, shallow groundwater is generally encountered at approximately 60 feet bgs, although historically groundwater was as shallow as approximately 15 feet bgs. Groundwater pumping is extensive in the areas surrounding the former base.

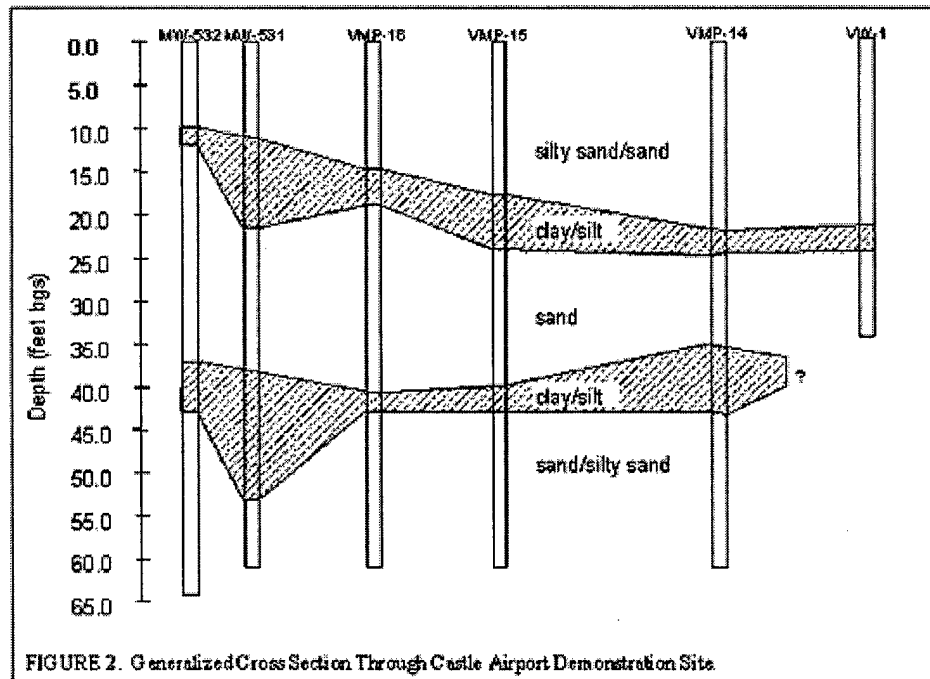


FIGURE 2. Generalized Cross Section Through Castle Airport Demonstration Site.

The maximum contaminant concentrations measured in soil at the site are 28,000 mg/kg total petroleum hydrocarbons (as gasoline), 12 mg/kg benzene, 293 mg/kg total BTEX (benzene, toluene, ethylbenzene, and xylenes), and 18 mg/kg naphthalene. Contaminant concentrations were generally higher below 25 feet bgs, consistent with the site conceptual model that vadose zone contamination resulted from a declining groundwater table which created a smear zone of contaminants.

For vadose zone soil samples, soil moisture content ranged from 1.5 to 26.7 percent (%) by weight, with an average soil moisture content measured at 11.1%. Moisture contents generally correlated with grain-size, with the higher moisture contents measured in the finer-grained materials (silts and silty sands). The average moisture content of the near-surface silt and silty sands is 15.8%, while the average moisture content of coarser-grained materials, found generally below 25 feet bgs, is 7.0%.

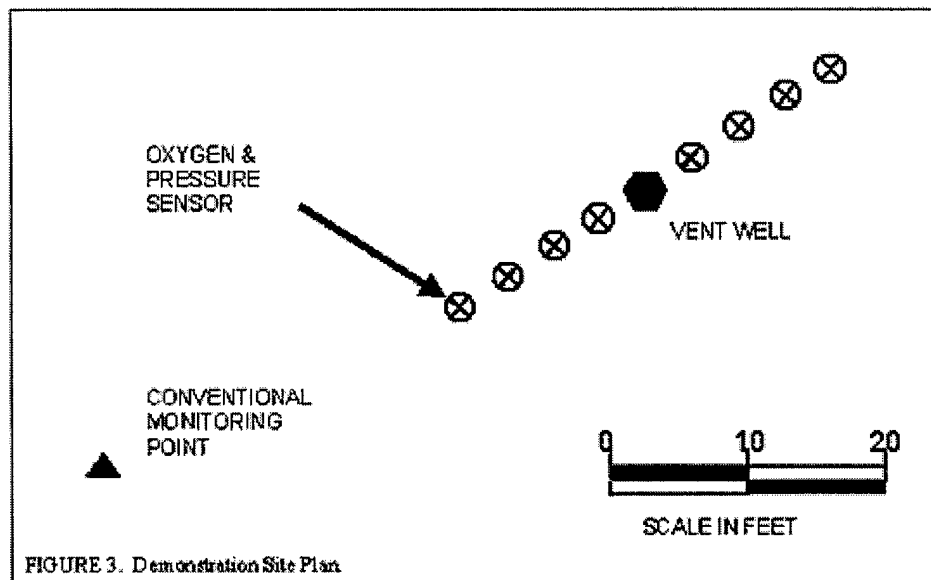
Oxygen concentrations in soil vapor are generally less than 1% in the contaminated areas while concentrations in the background soil vapor are above 19.0%, indicating there is very little natural oxygen demand in the soil. This measured oxygen-depletion in the contaminated soil is an indication of microbial activity and an indication that microbial growth is currently oxygen-limited. To promote *in situ* biodegradation of fuel residuals by increasing the oxygen concentration in the subsurface, conventional bioventing was selected during the feasibility study as the preferred remedial option for the site.

During a bioventing pilot test conducted at the site as part of the remedial design, it was noted by the field geologist that wells at the site were exhaling and inhaling air at various times during the day. In addition, during air permeability testing, the field scientist noted that changes in barometric pressure were clearly affecting the pressure measurements used to infer radius of influence and calculate air

permeability. Based on these observations, more extensive measurements and tests were recommended to determine the potential radius of oxygen influence due to barometrically-induced air flow.

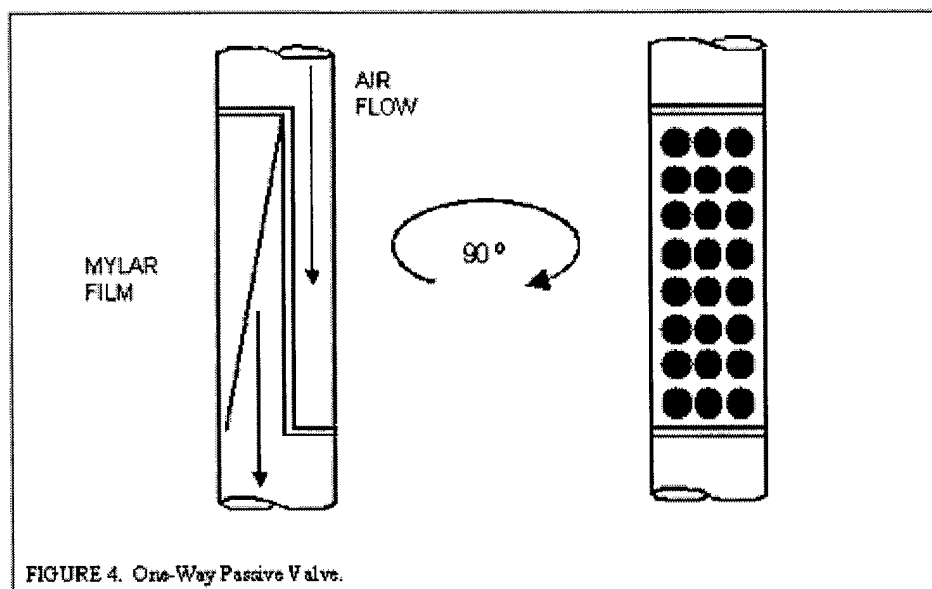
## Demonstration Methodology

The initial phase of the demonstration consisted of installing one vent well (VW) and eight monitoring points (MPs) as shown on Figure 3. The VW was screened between 25 and 65 feet bgs, below the near surface silty sand and clay/silt layer (Figure 2). A total of eight MPs, consisting of two radial arms each with four MPs, were installed adjacent to the VW. The four MPs along each arm were located at distances of 4, 8, 12, and 16 feet from the VW to evaluate changes in oxygen concentration with distance. Each of the MPs is constructed of isolated, depth-discrete screens to allow for multi-depth monitoring. Screens at the four innermost MPs (i.e., those located at 4 and 8 feet from the VW) are installed at 10, 30, 45, and 60 feet bgs. Screens at the remaining four MPs (i.e., those located at 12 and 16 feet from the VW) are installed at 30 and 60 feet bgs.



At each of the 24 MP depths, a directly-buried oxygen sensor (Datawrite Research Corp. model XTM253SP) with an integrated sampling and pressure measurement port is installed. Bidirectional pressure transmitters (Dwyer model 607) are used to measure subsurface differential pressure at each location and a K-type thermocouple is used to measure ambient temperature. An air flow transducer (TSI model 8475) is installed at the surface to measure air flow into and out of the VW. A data acquisition system with an integrated barometric sensor (In-Situ, Inc. Hermit model 3000) is used to collect and store all measurements in real time.

A one-way, passive valve (Foor *et al.*, 1995) was constructed and used during testing to enhance the potential treatment radius (Figure 4). The one-way, passive valve allows air to enter the VW only when pressure in the subsurface is lower than atmospheric pressure (a negative differential pressure). When the reverse gradient occurs, the valve closes to prevent the exhalation of previously injected air.



The data acquisition system collects and stores the following data every 10 minutes:

- barometric pressure;
- air flow rate in the VW;
- differential pressure at each MP screen;
- oxygen concentration at each MP screen (directly-buried sensors);
- ambient air temperature; and,
- groundwater elevation (at a nearby monitoring well).

Installation of the VW, MPs, and the data acquisition system were completed in April 1998. A series of tests are currently being conducted at the site. A summary of these tests is provided below:

- Test 1: VW closed (no air flow; control test)
- Test 2: VW open without passive valve installed
- Test 3: VW closed (equilibrium/respiration)
- Test 4: VW open with passive valve installed in injection mode

Test 1 is designed to evaluate the effects of barometric pressure fluctuations on subsurface oxygen and pressure without any system enhancement and was used as a control condition for all subsequent tests. Test 2 is designed to evaluate subsurface oxygen response and air flow rates both into and out of the VW without the use of a one-way valve. Test 3 is required to allow the system to reach equilibrium between Test 2 and Test 4 and was also used to measure microbial respiration rates and potential biodegradation rates at the site. Test 4 was the primary test for the passive bioventing demonstration and evaluated the effect of the one-way valve.

## Results

A plot of subsurface pressure response due to changes in barometric pressure is shown on Figure 5. The plot was developed from data collected during Test 1 conducted in late May and early June 1998 when the VW was closed. The plot shows both diurnal barometric pressure changes as well as a minor weather front-related barometric pressure increase (between May 28 and May 31). Subsurface differential pressure response is shown for 2 depths, 10 feet bgs and 30



feet bgs. As expected, the differential pressure is negative at both depths during periods of increasing barometric pressure and positive during periods of decreasing barometric pressure. The magnitude of the subsurface differential pressure is significantly greater at 30 feet bgs compared to 10 feet bgs. However, the magnitude of the response at 30 feet bgs was essentially identical to that at 45 feet and 60 feet bgs in all MPs (a plot of the data from 45 and 60 feet bgs would be indistinguishable on Figure 5 from the data at 30 feet bgs). Therefore, the significant influence on subsurface differential pressure factor at this site is not depth, but rather the geological stratification, more specifically, the overlying lower permeability silty sand between 0 and 15 feet bgs and clay/silt layer between 15 and 25 feet bgs (Figure 2).

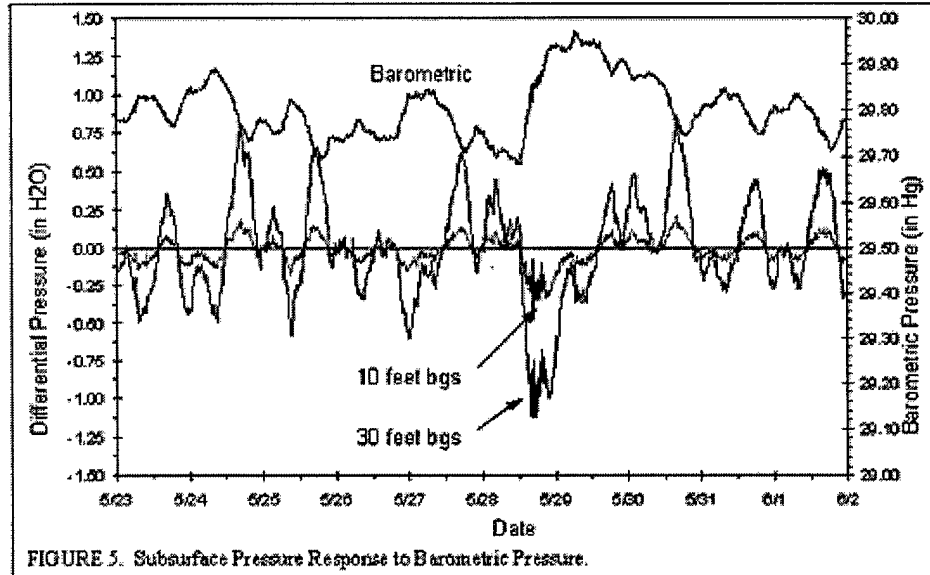
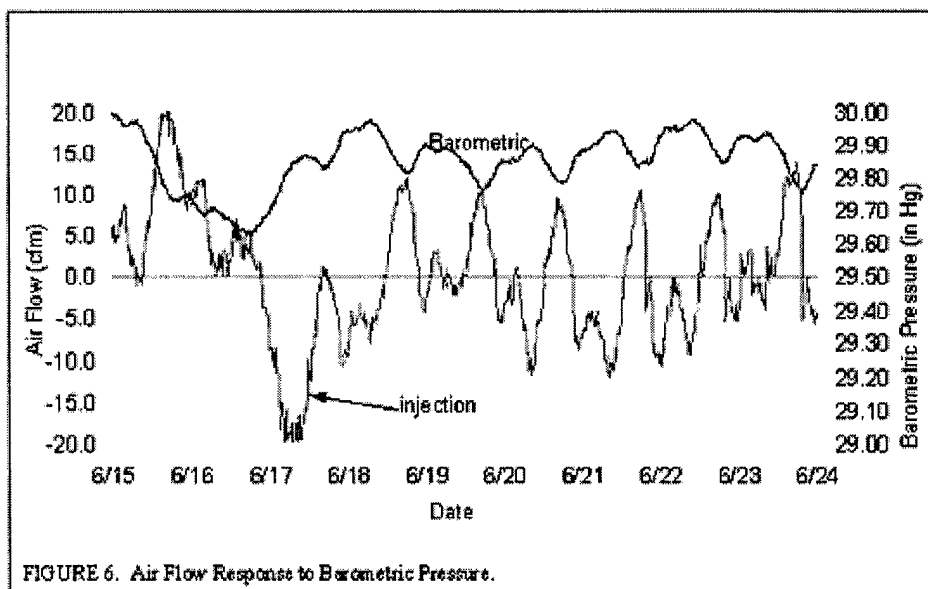
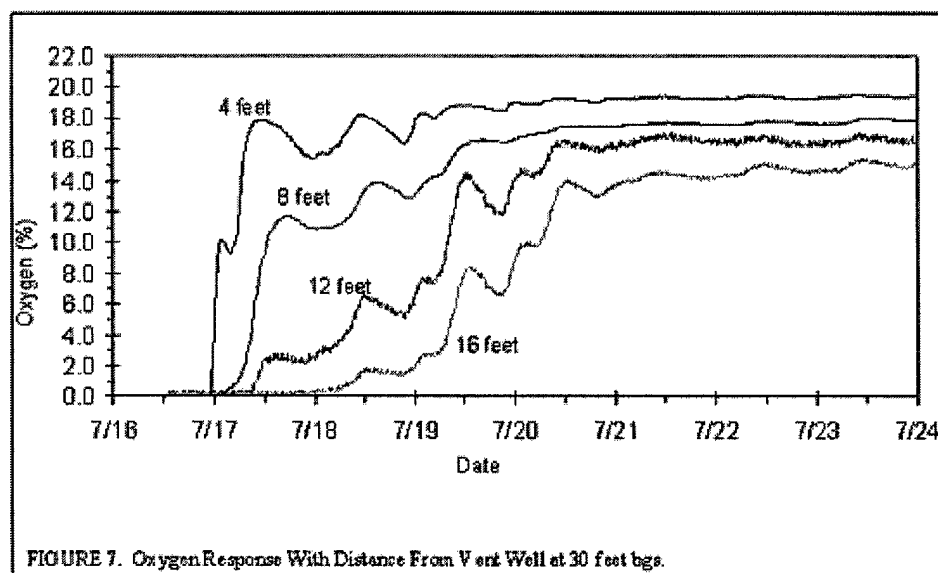


FIGURE 5. Subsurface Pressure Response to Barometric Pressure.

A plot of air flow due to changes in barometric pressure is shown on Figure 6. This plot was developed from data collected during Test 2 conducted in mid to late June 1998 when the VW was open to the atmosphere but air was allowed to flow both into and out of the well (i.e., no one-way valve was installed). The plot shows a relatively significant weather front-related barometric pressure change during the first three days of the test, followed by primarily diurnal barometric pressure changes. Both the weather-front and diurnal barometric pressure changes resulted in significant air flow both into and out of the VW. Air flow rates as high as 20 cfm occurred during the weather front changes and rates as high as 12 cfm occurred during diurnal changes. These air flow rates are comparable to typical air flow rates used during conventional bioventing (USEPA ORD, 1995) and clearly demonstrate the feasibility of using a passive bioventing approach at this site.



A plot of subsurface oxygen response at 30 feet bgs due to air flow is shown on Figure 7. This plot was developed from data collected during Test 4 conducted in mid to late July 1998 when the VW was open to the atmosphere but air was allowed only to flow into the well (i.e., the one-way valve was installed). The figure presents data from one of the radial arms of MPs installed away from the VW (see Figure 3). The four MPs along this arm are located at 4 feet, 8 feet, 12 feet, and 16 feet distance from the VW. As expected, there is a progressive increase in the time for the oxygen response to occur related to the distance from the injection point. However, within a relatively short period of time oxygen concentrations increased from less than 1% to greater than 15% at each MP.



Long term air injection from the VW showed increases in oxygen concentration of 5% as far away as 42 feet from the VW (as measured at the conventional bioventing MP shown on Figure 3). Oxygen is generally not considered the limiting factor in microbial growth at concentrations greater than or equal to 5% (USEPA ORD, 1995), indicating that the treatment radius from a passive bioventing approach at this site is potentially as high as 40 feet.

## Conclusions

Preliminary results from the passive bioventing demonstration at Castle Airport have indicated that both short-term diurnal changes and long-term weather front changes affected both air flow and subsurface differential pressure. The magnitude of the differential pressure was higher in the deeper, more permeable soils compared to the shallower, lower permeable soils. However, the differential pressure did not increase with depth in the deeper soils, evidence that the geological stratification at the site has a more significant influence than depth on differential pressure and air flow.

Natural barometric pressure changes induced subsurface differential pressure gradients as high as 1.1 inches of water and air flow rates as high as 20 cfm into and out of a vadose zone vent well. Based on increases in oxygen concentration of 5% as far away as 42 feet from the injection point, which is sufficient to meet the microbial demand needed for in situ biodegradation, passive bioventing has the potential at this and similar sites to be an economically feasible alternative or companion technology to conventional bioventing.

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# **The Trials and Tribulations of Multi-Agency/Joint Services Installation Restoration Program Partnering**

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The authors of this paper are Ramona Wilson, an Environmental Program Manager in the Air Force Eastern Regional Environmental Office in Atlanta, and Jamie Higgins, who is associated with the Army Southern Region Environmental Office and represents the DoD Regional Environmental Coordinator for Region IV. This paper presents the history and our experiences with Multi-Agency/Joint Services Installation Restoration Program (IRP) partnering that we have been instrumental in establishing in Region IV.

## **Why Partnering?**

When the concept of partnering was first considered, the IRP for DoD installations in Region IV was in serious trouble. The adversarial relationship that had developed between the installations and the regulators was so strained, that essentially, communication had broken down and the cleanup program was going NOWHERE. Each side was securely encamped, lobbing official letters bombs at each other. Something had to be done to get the program on the right track. The concept of partnering between contractors and government agencies had been established and demonstrated by the Corps of Engineers on construction projects, and it was hoped that the success achieved on these projects might be transferred into the cleanup program. Though not exactly equivalent, the programs have enough similarity that it was considered worth a try.

## **What is Partnering?**

Over the years, partnering has been defined in a number of ways. Essentially, a Partnering Team is a group of people working together on a common project in such a way that everyone benefits, and the project is completed "Faster, Cheaper, and Better." However, partnering is not just people working together on a project. Partnering includes tools, procedures, and empowered team members. In addition, a key element of a Partnering Team is the development of a means of dealing with conflict. When a disagreement occurs, the members of a Partnering Team don't just "take their bat and ball and go home," they jointly work through the problem. Oftentimes conflicts arise due to miscommunication, so when members of a Partnering Team are sitting nose to nose with each other, and using the tools they have acquired through team development training, they are more likely to identify the miscommunication, rather than continuing to hold to incorrect assumptions.

As I previously stated, partnering began in DoD with construction projects in the 1980s. In 1993, the Federal Facilities Environmental Restoration Dialogue Committee issued the Keystone Report. This report states:

"Because federal facilities cleanup issues are so complex, federal agencies, state, tribal, and local governments, communities, and other stakeholders must forge partnerships that will enable our nation to make the best decisions possible to address environmental contamination at federal facilities. Through collaborative processes, the federal government and its stakeholders will rise to the challenge posed by federal facilities cleanups . . ."

The recommendations of this report have been embraced by DoD, EPA and several states to improve the execution of the Cleanup Program at DoD installations within Region IV.

## **Region IV IRP Partnering Timeline**

- 1980s USACE/Navy use partnering on Construction Projects
- 1993 The Keystone Report (FFERDC)
- 1993 Navy implements partnering in Region IV
- 1995 USAF implements partnering in South Carolina followed by Florida and a Regional Tier III Team
- 1996 Single Service Partnering Teams started in AL and MS
- 1996 EPA and SC Request a Trial at Establishing Joint Services Three-Tiered Partnering
- 1997 Training Provided for Teams from the Army, USAF, and Navy/Marines in SC, AL, NC, and MS with existing Tier II Teams converted to Joint Services Partnering Teams
- 1997/98 Pollution Prevention Partnerships started in Several States

## **Why Joint Services Partnering?**

Joint Services Partnering was initiated primarily due to a lack of State and EPA resources. In South Carolina there were separate Navy and Air Force partnering programs, and there was considerable pressure being put on the Army to also initiate IRP partnering. The State wanted to continue the program, but the number of meetings involved with partnering was stretching their staff too thin. South Carolina indicated that they might have to scale back on their involvement. It was therefore proposed that the Navy and Air Force programs merge, and that the Army join this new Joint Services Partnering Program. This would minimize the number of meetings that State and EPA personnel would need to attend, and it was believed that the new program would bring more consistency and coordination to the Cleanup Programs across the DoD Services. Also, it assured the State and EPA that each of the Services was receiving the same message, at the same time. The Component Regional Environmental Coordinators from the Air Force, the Navy, and the Marine Corps, and the DoD REC for Region IV from the Army have provided the organizational backbone for this new program.

## **Region IV IRP Partnering Structure**

Joint Services IRP Partnering in Region IV has a 3-tiered structure. At the Regional or Tier III Level, there is a 13-member Steering Committee composed of the EPA Region IV Federal Facilities Branch Chief, the DoD REC, the Component RECs from the Air Force, Navy and Marine Corps, and upper management representatives from several of the State environmental regulatory agencies.

The Full Tier III Team, with about 50 members, includes: the Steering Committee;

representatives from the Air Force Major Commands with installations in Region IV; the Army Major Commands with posts in Region IV; the Southern Division of the Navy's Facilities Engineering Command; and Service Center representatives from the Air Force Center for Environmental Excellence (AFCEE) and the Corps of Engineers.

Tier II is the State Level. Tier II teams vary in structure from state to state depending upon the DoD installations located within each state, and the status of IRP cleanups at the installations. For example, the South Carolina Tier II Partnering Team is truly a Multi-Agency/Joint Services Team. Within South Carolina are: 2 fully active Air Bases, a closing Air Base and the Air National Guard; an active Naval Station, a closing Naval Base and Shipyard, 2 fully active Marine Corps installations, and Ft. Jackson. Included in the Tier II Team are: the environmental flight chiefs from the active Air Bases and representatives from their Major Commands; a representative from the Air Force Base Conversion Agency; the environmental director for the SC Air National Guard; the environmental director from the Naval Weapons Station; a representative from Ft. Jackson's Major Command; a representative from the Naval Facilities Engineering Command Southern Division; personnel from the USACE from Kansas City and Savannah; representatives from each of the component RECs and the DoD REC; various personnel from the SC Department of Health and Environmental Control; and a representative from Region IV EPA.

The installation level is where most of the work associated with the IRP occurs; therefore, the Tier I Partnering Teams are composed of the installation level Remediation Program Managers from the base, State, and EPA, the Service Center representatives, and the remediation contractors. The Air Force Tier I Teams also include a Major Command RPM. The Tier I Team members are the people who are involved in the day-to-day operation and management of the IRP. The individuals on these Partnering Teams are empowered by their managers and supervisors to make the decisions that accomplish the cleanups at the installations.

## **Partnering Comparisons**

- At Ft. Jackson between 1993 and 1997, no work plans were reviewed by the State. Partnering was initiated March 1997. Within a year, Ft. Jackson had received no further action (NFA) approvals for 21 sites; investigations were completed at 19 sites; 17 RFI investigations are now in progress; and the regulators have reviewed all work plans.
- Shaw AFB has estimated over \$2 million savings as a direct result of the partnering initiative. In addition, document review time has been reduced about 210 days per site, and regulators have approved the elimination of some studies that had previously been required.

A very conservative estimate performed for the Air Force partnering initiative in Florida indicates that IRP Partnering has had a 10:1 return on investment. For every \$1 spent on outside facilitators, TDY expenses, staff time, training, etc. there has been a \$10 savings towards the cost of the Cleanup Program.

## **Partnering Tools**

- Frequent Communication/Meetings
- Team Building/Development Training
- Meeting Management Tools
- Consensus Agreements
- Model Documents

- Face-to-Face Document Review
- Empowered Team Members

Partnering Teams must meet and communicate on a regular basis. They need to go through Team Building/Development and Partnering Training. This training cannot be accomplished solely in a single workshop, but must include continuing, periodic training. Many teams put a training exercise on their standard meeting agenda to be conducted each time the team meets. The teams need to develop Meeting Management Tools, and establish protocols to ensure meetings are run efficiently. Decisions need to be made based on consensus. Unilateral decisions are not indicative of Partnering. Model documents can greatly reduce the work effort both to produce documents such as Work Plans and to focus regulator review on the areas that actually need their attention. The model documents can initially be developed in skeleton form by the contractors, but the team should work together to determine final format and how the data and results should be presented. If this is done, the written reports merely become a means of archiving the decisions and work, rather than the bulk product of the work.

Key to any successful Tier I Team and Cleanup Program is empowerment of the RPMs—installation and regulator. Realistically, there will be times when RPMs need to consult with upper management on some decisions—especially those that involve policy or establish precedent; but as much as possible, all day-to-day program decisions should be made by the RPM and supported by their chain of command.

## **"T.U.R.N.I.P.S." (Things You Really Need In Partnering Success)**

Based on the experience gained as the partnering program has developed, there are several items that are crucial to the success of the partnering effort. Some of these are:

- Ground Rules
- Established and Defined Roles and Responsibilities for Each Team Participant
- Goals and Objectives
- Norms—Ways of Working Together
- Standard Meeting Agenda and Minutes
- An Understanding of the Expectations of the Other Partnering Teams within the Tiered Structure
- Communication Links to the Other Partnering Teams within the Tiered Structure
- Graduation Criteria
- Training Needs

These are the meeting management tools that each team needs whether they are Tier I, Tier II or Tier III. When we decided to form Joint Services Partnering Teams, the Tier II was formed first, and we had to figure out how to run our meetings, establish goals, and form the foundation necessary to establish and support the formation of the Tier I Teams. Our main goal during the first year was to get the Tier I Teams trained in the "Basics of Partnering." Training was provided by personnel from Management Edge, Galileo, and Smith Strategic Corporate Psychologies. These firms have also been contracted through various methods to provide facilitators and ongoing training to the Tier I and Tier II Teams. At the Tier I level it is expected that a Team may become a "highly performing team capable of self-facilitation." If they meet certain criteria, they



may be "graduated" to self-facilitation.

## **Partnering Accomplishments**

**Joint Services Partnering Training.** Four Tier I Teams received the Basics of Partnering Training January 1997. This marked the first time that Teams from each of the military services received training of this type together. The four Tier I teams that received this training represented Ft. Jackson, Charleston AFB, Parris Island, and Beaufort MCAS. In addition, the Tier II team for South Carolina, some new members from the previously existing Tier I Teams, and several representatives from Tier III attended the workshop. Since January 1997, Joint Services Partnering Training has been offered to other states within Region IV-North Carolina, Alabama, and Mississippi.

**Networking.** The partnering program allows extensive networking between representatives from the military installations, regional environmental offices, and State and EPA.

**Joint Teams Workshop.** SC and DoD sponsored an Environmental Workshop, June 1998 at MCAS Beaufort, SC. Approximately 50 people representing each of the DoD installations in SC, and SC DHEC attended the Workshop. Presentation topics addressed technical issues, regulatory concerns, and "lessons learned." A similar Workshop is being planned for NC.

**Access to the Rulemaking and Policymaking Process.** The power of numbers is illustrated by the increased access of the Joint Services Tier II Teams to the persons within the State governments that are involved with establishing policy and developing laws and regulations. With this high level of access, DoD is able to influence the processes at early stages, rather than reacting to proposed regulations during public comment periods. At the recent SC/DoD Joint Teams Workshop, SC DHEC and the Region IV DoD REC provided a panel of senior managers within DHEC. Panel members included: Bob King, the Assistant Deputy Commissioner; Harry Mathis, Assistant Bureau Chief of Land and Waste Management; David Baize, Director of Division of Water Monitoring, Assessment; and, Michael Rowe, Director of the DHEC Policy and Planning Division. George Carellas, the DoD REC for Region IV also participated on the panel. The panel received and responded to a number of issues of importance to the environmental programs at DoD installations in SC.

Also, Mr. Rowe attended SC Tier II Team meetings in October 1996 and June 1998, to discuss the Legislative Package preparation process; the contents of the Legislative Package for the 1997 Legislative Session, and the results associated with the actions of the 1998 Legislative Session. South Carolina is one of the few states in the nation where all environmental regulations are developed and passed by the State Legislature. Due to the complexity of the regulations/laws, sometimes items that are needed by DHEC may be revised by legislators in such a way as to limit their effectiveness, or may be dropped due to insufficient time for consideration. Mr. Rowe has encouraged the partnering team to get involved in helping his office develop the regulations/laws.

**Information Exchange.** During each Tier II meeting, the Host installation is asked to provide a presentation on the status of the IRP. Meetings also include technical presentations regarding new technology, regulatory explanations, status updates on issues under negotiation between regulators and installations, and reports from each Tier I Team via their Link/POC to the Tier II Team. With each topic of discussion, there are often handouts provided. The handouts are bundled

with the meeting notes and distributed to each Team member and to contacts on each of the Tier I Teams and the Tier III. Other methods of information exchange are less formal. Team members often discuss problems with other members during breaks, meals, and social activities.

**Team Development Training.** Team development training is an ongoing benefit of the partnering process. The facilitators provide instruction on ways to deal with conflict, how to relate to persons according to their personality types, and ways to improve the management of meetings and the accomplishment of goals and objectives.

## Other Partnering Accomplishments

	Tier
Land Use Controls Action Plan (LUCAP) EPA Region IV Policy	III
Institutional Controls Agreements	II
Rotation of Host for Meetings	I,II,III
Trust	I,II,III
Time Savings	I
Cost Savings	I
Adoption of the Military Munitions Rule	II, III
DSMOA/CA	I, II
Pollution Prevention Partnering	II
Closure of Sites	I
Metrics	III
Excavation	II

The results of the IRP Partnering Program in Region IV have had far-reaching affects. The issue of the use of institutional controls for sites at active bases that cannot be cleaned up to residential standards, led to the establishment of the EPA Region IV LUCAP Policy. Adoption of the Military Munitions Rule by the states in Region IV has been aided by the high level of interaction occurring between regulators and the Service RECs as a result of IRP Partnering. The IRP Partnering has also led in the past year to the establishment of State/DoD Pollution Prevention Partnering Programs in South Carolina and Georgia. Other states have also expressed interest in participating in State/DoD Pollution Prevention Partnering Teams.

## Challenges to Partnering Implementation

- Money and Support from Upper Management
- "Fluff" vs. "Substance"
- We're already Partnering!
- Bureaucracies and "Turf" Issues

- Time Commitment
- Overcoming History of Adversarial Relationships
- Personalities
- Lack/Violation of Trust
- Anti-Partnering Attitude
- External Facilitators
- Stamina

For IRP Partnering to be successful, it must have support from Upper Management in each of the participating organizations. The additional meetings and the hiring of a facilitator impact the cleanup budgets; however, as previously stated, it has been estimated that partnering saves money and time overall. Engineers and scientists often perceive the team development training activities and the development of items such as Mission Statements as "Fluff" which doesn't contribute to getting the job done. Overcoming this bias can only be accomplished over time as the tools obtained by these activities are used and found to contribute to dealing with problems. Many teams that hold regular meetings with regulators and are getting the cleanup program done, believe that they are already partnering. Experience has shown; however, that these teams may be operating somewhat efficiently as long as everyone is in agreement, but when these teams disagree, they do not have the tools necessary to deal effectively with conflicts. Often, the most difficult ground rule to comply with, is the necessity of "Staying through the Hard Parts." However, when a team works through a conflict to a consensus decision, there is an enormous sense of satisfaction and accomplishment that is shared by all.

## Other Benefits

- Installation Tours of Cleanup Facilities
- Scenic Locales at DoD Installations
- Camaraderie and Social Activities
- Frogmore Stew and Beer—a Low Country delicacy
- Barbecue—comparison of the different styles of barbecue
- The Post Meeting Recovery Hour—drinks on the porch overlooking a river and a salt marsh

## Quotes

"Its good to bring together the regulators and the military in one place. It helps build better relationships."—*George Carellas, Region IV REC*

"The Team's dialogue has been honest and straightforward, with little posturing and positioning. This has brought DoD, EPA, and the State to an understanding of each other's concerns and needs as rapidly as it could have been done."—*Grover Nicholson, NC DENR*

"They give me voluminous reports, but during those monthly meetings, I find out what's important. This really helps me focus my reviews and prioritize my work. It also helps me decide when I need the expertise of other state agencies."—*State RPM*

"It used to take years to get reports reviewed and approved by the state, now it only takes months, sometimes only weeks."—*Base RPM*

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# **Innovative Techniques to Emplace Zero-valent Iron**

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## **Abstract**

In October and November 1997 two different techniques were used to install pilot-scale reactive iron filings walls at Cape Canaveral Air Station (CCAS), Florida. The demonstration walls were installed in a plume near Hangar K in the industrial area of CCAS. Trichloroethylene, and its daughter products, have created a plume of contamination at the site. The emplacement techniques abut each other creating a continuous 100 foot main wall cutting off a portion of the plume. Both emplacement techniques went to a 45 foot depth and used the same overall layout. Each has a 50 foot main wall followed by a second 10 foot wall placed four feet downgradient from the main wall and a third ten foot wall four feet downgradient from the second wall giving a total target length of 70 linear feet for each technique. The second and third walls were centered behind the main walls. Dedicated in-situ flow sensors and groundwater monitoring wells were installed after construction activities to track the performance of these walls.

The first technique used a hollow mandrel or vibrated beam to create a 4 inch thick void space approximately 45 feet deep and 34 inches long. A disposable shoe acted as a lead drive point on the 7-ton mandrel. A vibratory hammer drove the beam to depth and dry iron was loaded into a chute at the top of the mandrel. Wall continuity was maintained by overlapping adjacent wall panels. Approximately 98 tons of iron were emplaced in 9 days. Operational and alignment problems initially plagued the process, but these were resolved and operational cycle times (time to install one panel) were just under an hour. A total of 32 panels were installed creating 76 linear feet of reactive walls at the site without generating any spoils.

The second technique emplaced the iron as a slurry by mixing it with guar gum and a binder. A 36 inch I-beam was used as a guide tool to get a high/low pressure nozzle down to 45 feet. Water jets in the high pressure side of the nozzle were designed to aid in creating the void space for the beam and subsequent iron slurry. A vibratory hammer was used in addition to the water to drive the beam to depth. Again wall continuity was achieved by overlapping the panels. The iron slurry was created and pumped through the low pressure side of the nozzle. Approximately 110 tons of iron were emplaced in 12 days. Maintaining a consistent iron density in the slurry and a constant volume of injected material was a problem throughout the demonstration. Operational cycle time was approximately one hour. A total of 24 panels were installed creating 64 linear feet of reactive walls at the site, generating approximately 4,000 gallons of liquid and 24 tons of solid wastes.

## Background

In recent years it has been shown (Gillham and O'Hannesin, 1994, and others) that chlorinated organics in the groundwater can react with zero-valent iron in situ and, given enough residence time, completely degrade the contaminants into harmless organic molecules. Emplacement techniques in the past have usually focused on excavate-and-replace methods for either continuous walls or funnel-and-gate wall designs. Typical construction processes have limited ability to go deep, even beyond 35-40 feet. The challenge then was to get the reactive media deeper in a cost-effective manner. Hubble *et al.* (1997) reviewed several different emplacement techniques for work at the Massachusettes Military Reservation (MMR) where trichloroethylene (TCE) contamination exists to 120 foot depths. Their conclusion was vertical fracturing was the cheapest alternative for that site at the MMR.

The other technologies that were evaluated for MMR included vibrated beam (or mandrel), deep soil mixing, and typical slurry wall construction. The last two would take advantage of the equipment and knowledge base to emplace impermeable walls with bentonite to tackle the problem of emplacing iron. The mandrel is typically used to emplace wick drains to dewater soils, but its hollow shaft would allow adding the iron to the subsurface in a dry form. The technologies chosen for this field demonstration were the mandrel method and an innovative jet-assisted grouting process.

## Demonstration Site Characteristics

The site is located in the industrial portion of Cape Canaveral Air Station (CCAS) FL near Hangar K. The groundwater table fluctuates between four and six feet below ground surface (bgs) with an aquitard at 43-44 feet bgs. The soils are primarily sands with interspersed layers of silts, clay, and marl. The aquifer is moderately heterogeneous, with orders-of-magnitude concentration changes in as little as three feet of depth. The relatively flat groundwater gradient in the area resulted in permeable, but slow, groundwater seepage velocities on the order of 0.1-0.05 feet per day. The slow rate of travel allowed for thin walls to be emplaced, opening the way for innovation in emplacement techniques.

The pilot-scale walls were constructed in late 1997 in two field efforts to minimize site clutter in creating this side-by-side demonstration. All of the walls went to a depth of 45 feet. Figure 1 illustrates the layout of the walls and the monitoring system used to determine system performance. Trichloroethylene (TCE) (and its degradation by-products) are the contaminants of concern and are across the site to a depth of 40 feet bgs. Concentrations range from 0-400 ppb total VOCs in the shallow zone (15-20 feet bgs) and from 90,000 to 180,000 ppb total VOCs in the deeper zone (35-40 feet bgs). Both zones are contaminated with predominantly cis-DCE and vinyl chloride with minimal amounts of TCE.

The shallow and deep zones have similar background characteristics, with the exception of the electrical conductivity (EC). The EC for the shallow zone is in the 300-400  $\mu\text{mhos/cm}$  range while the deep zone is in the 800-1200  $\mu\text{mhos/cm}$  range. The pH typically is 7.5-8 with dissolved oxygen levels being very low (0.2-0.5 mg/L). The Eh also indicates a very reducing environment, typically in the -100 mV range.

## Emplacement Techniques

The first emplacement technique installed iron using the mandrel process. Slurry Systems, Inc. (Gary, IN) fabricated the 14,000-pound mandrel out of three channel iron segments and two end plates giving an overall I-beam shape to the tool. A 140-ton Manitowac crane and guide assembly were used to keep the mandrel aligned during the insertion and extraction steps. A disposable shoe covered the opening on the leading edge of the mandrel while a 150-hp electric vibratory hammer drove it to depth. This opened a 34-inch wide by 4-inch thick swath in the subsurface without creating any spoils.

Once the mandrel was driven to depth a bag of iron (1½-ton "super bag") was loaded into a chute near the top of the mandrel. The iron was allowed to freely fall into the mandrel in any of the three openings at the top. There were cutouts in the bottom parts of the channel iron to allow iron to flow between the three chambers. These cutouts extended for about 12 feet up into the mandrel. After the first bag was loaded the shoe was forced off using a pneumatic pump and a long center rod that was retracted during the driving step. A second bag was loaded and the mandrel was vibrated out to facilitate even distribution of the iron among the different chambers. The panels overlapped one another by 4 inches to ensure a continuous wall. Cycle time, the time to complete one panel to start of the next one, was between 45 and 60 minutes.

The second emplacement technique was the jet-assisted grouting process. Foremost Solutions (Golden, CO) used a jetted I-beam to place an injection port at depth. A crane was used to hold the vibratory hammer/I-beam assembly. There was no additional rigging to maintain alignment on the crane as in the mandrel process. High pressure water jets on the side of the slurry injection nozzle forced out water at pressures up to 6,000 psi at 20 gallons per minute. Most of this water went into the formation, but some carried the cut material to the surface where it was siphoned off. Approximately 4,000 gallons of liquid and 24 tons of solid spoils were generated during this portion of the demonstration.

After the I-beam was driven to depth a steel plug, used to protect the injection port opening during the insertion step, was forced off the bottom by means of a rod on a rope. The iron slurry was pumped through a line along the length of the I-beam to the leading edge where it was injected into the formation. The injection pressure and the overpressure of the slurry above the injection point caused the I-beam slot to be filled and expanded while the beam was being withdrawn. Panels were inserted in a leap-frog approach to keep the same forces on both sides of the beam flange (either both soils or both iron slurry). Adjacent panels overlapped one another to create a continuous wall. The iron slurry was a mix of water, iron, guar gum, and a borate binder making a viscous fluid with a density of approximately 190 pounds per cubic foot. The exact mix was difficult to control and a range of densities was used in the demonstration. The slurry was also abrasive to pumping equipment and tended to "pack off" (a situation where the carrier fluid is squeezed out of the slurry leaving an iron plug in the line). Cycle time was between 1 and 3 hours.

Table 1 gives the detailed parameters for the two techniques. Cost numbers are final figures and include costs of shipping any excess iron back to the supplier and the associated credit to the project.

**TABLE 1. Comparison of Different Emplacement Techniques Used at Cape Canaveral Air Station, Florida.**

	<b>Mandrel</b>	<b>Jet-Assisted Grouting</b>
Mobilization/Demob Costs	\$75,000	\$84,000*
Construction Costs	\$159,000	\$80,000
Iron Vendor	Peerless	Peerless
Iron Mesh Size	8 to -50	-16 to dust ("P1")
Tons of Iron Installed	98	110 (demo) + 12 (test area)
Length of Wall Created, Feet	76	64 (demo) + 8 (test area)
Iron Costs	\$56,000	\$80,500*
Set up time	10 days	12 days*
Construction time	9 days	12 days
Liquid spoils	None	4,000 gallons
Solid spoils	None	24 Tons
Spoils Disposal Cost	\$0	\$35,900
Total Costs	\$290,000	\$280,400
<i>* Includes cost/time for test area in clean soils.</i>		

## Performance Evaluation

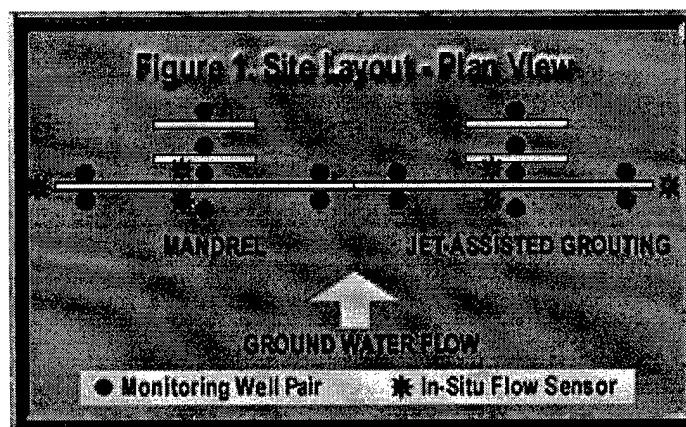
The expected performance for the walls was based on the Lowry AFB, CO (AFCEE, 1997) and Moffett Field, CA (NFESC, 1998) sites among others. The geochemical parameters inside the reactive media should have decreased the dissolved oxygen (D.O.) levels, increased the pH, decreased the sulphate and carbonate levels, produced ethylene in measurable quantities, and slightly increased the dissolved iron concentrations. Downgradient of the walls at these sites some conditions tended to return to upgradient conditions, most notably the pH. For the mandrel technique several attempts were made to place small diameter monitoring wells inside the 4-inch thick wall as part of the construction process but failed due to the stresses created during installation. The jet-assisted grouting process does not allow any opportunity for these observation points. Therefore, only up and downgradient wells are available for performance monitoring.

After the walls were installed dedicated flow sensors (HydroTechnics, Inc., Albuquerque, NM) and groundwater monitoring wells (multi-level; shallow at 15-20 feet bgs and deep at 35-40 feet bgs) were placed at strategic points to monitor the performance of these new reactive cells (see Figure 1). The entire site was allowed to settle and adjust to all these changes to the subsurface until February 1998.

Two types of sampling were conducted at the site. Inorganics, geochemical parameters, and water levels were measured monthly while the VOCs were measured quarterly. The bulk of the parameters have not changed much over the six months of monitoring. The expected trends have not been consistently



observed. This is due in part to the background conditions being so reducing. For example, when the aquifer starts at a dissolved oxygen level of 0.2 mg/L, it's not easy to detect a major downward shift. In addition, the upward shift in the pH observed in most reactive barriers occurs inside the reactive media itself. Once the water exits the wall the formation rapidly buffers any pH changes as has been shown at Lowry and Moffett. There has been a slight change down gradient of the walls in the alkalinity of the groundwater, but on average the monthly fluctuations are greater than any differential seen across the wall. The Eh on average drops 20 to 50 mV across the wall sections in both the upper and lower zones. Concentrations of ethylene (up to 4.5 ppm) and acetylene (up to 80 ppm) have been noted in the headspace of certain wells in the jet-assisted grouting portion of the walls. It is suspected that these wells actually are in communication with the iron filings due to possible bulging of the iron walls noted below.



The levels of organics have been measured twice (February and May) and conclusions based on this limited data set have not been made. There are some trends noted, however. These include an average increase of 27 percent in the influent concentration (total VOCs) into the main (long) wall segment. This may be due to the decline in the water table or changes in the source. In February the long wall had an average reduction of total VOCs of 25 percent and in May it was up to 31 percent. It was expected that complete destruction of the organics would require passage through three wall thicknesses. Additional sampling will be done to verify the continued performance of all wall segments.

The flow sensor data has remained relatively consistent to date. The dedicated flow sensors are set in place, each at a depth of 40 feet bgs, and show a variety of responses. The units can measure both vertical and horizontal flow directions as well as velocity. The data has been difficult to interpret and may be due to heterogeneities of the aquifer or the low flow conditions of the site. The groundwater direction, based on piezometers, vary depending on which zone in the subsurface being observed. The flow direction of the deep zone appears to be perpendicular to the wall, while the upper zone flow is about 40 degrees off the line of the wall.

## Conclusions and Recommendations

Using equipment from other processes to emplace zero-valent iron has advantages and disadvantages. Control of the driven beams on both processes was hampered by the ability to measure the amount of angle on the emplaced tool. When working to create a 4-inch thick wall, a fraction of a degree means a lot, especially the deeper the wall.

The mandrel process used for this demonstration utilized heavy-duty equipment, driving the per-day construction costs quite high. The equipment caused noise and vibrations that affected nearby buildings and occupants, but no apparent structural damage was noted. The massive size of the equipment made fine tune control difficult in creating a continuous 4-inch wide wall. Additional rigging in the line of the wall would aid in alignment and speed up the operation. The iron is kept dry until added and the iron is placed at a known depth and thickness.

The jet-assisted grouting process used for this demonstration utilized a less costly crane system, but had a harder time maintaining initial alignment; several segments were redone because they were out of tolerance to maintain a continuous wall. The added rigging in the trench made shifting to a new position easier, but did not aid in controlling the angle of the beam during emplacement. The iron used for this portion contained more fine particles and was more susceptible to being blown by the wind causing eye safety problems. Extra precaution was needed when handling the dry iron. The iron was also abrasive to the interior segments of the pumping equipment and pack-off of the iron slowed the process. Due to the method of emplacement, the exact dimensions of the wall are unknown. It is expected that in the less dense, more permeable zones, the walls are thicker (wall bulges out) while the more dense clay layers have less iron, perhaps only the thickness of the I-beam used to drive the nozzle to depth. Spoils handling and disposal add additional costs to this installation technique. There were initial concerns about the guar gum-based carrier fluid interfering with the wall performance. This effect, however, has not been noted to date.

Continued work is needed to expand the methods used to emplace zero-valent iron into the subsurface. The processes here were suited to the site due to the slow seepage velocities that allow for thinner walls to be used. Sites with faster groundwater flow velocities will need thicker walls and different emplacement equipment will be necessary to achieve a thicker installation. Construction monitoring and quality control procedures will need to be very precise to be able to ensure a continuous wall below the 45 foot level used in this demonstration.

Additional sampling will be conducted to continue monitoring the performance of the walls. This includes continued water level and groundwater sampling. The data from the flow sensors is measuring a specific point in the aquifer and may be influenced by local conditions instead of the flow zones being monitored in this study.

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# **Evaluating the Performance of a Permeable Reactive Barrier**

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### **Abstract**

The permeable reactive barrier or treatment wall is an innovative technology for the remediation of groundwater contaminated with chlorinated hydrocarbons, such as trichloroethene (TCE), perchloroethene (PCE), dichloroethene (DCE), vinyl chloride (VC), and others. The technology is based on a general chemical reaction, in which zero-valent iron particles react with chlorinated hydrocarbons in groundwater to produce non-toxic, easily biodegradable, light hydrocarbon chain C2-C5 compounds (ethanes, ethenes, etc.), iron and chloride ions, and hydroxides. Remediation of contaminated groundwater by conventional pump-and-treat systems is usually very difficult, long-term, costly, and sometimes ineffective. The unique benefit of the permeable reactive barrier technology is that it can passively remediate the chlorinated hydrocarbons in groundwater using the natural flow properties of a site and no above ground structures or external energy are required. Permeable reactive walls have been identified by the U.S. Environmental Protection Agency (EPA) as an emerging technology<sup>1</sup> for cleanup of groundwater contaminated with chlorinated solvents.

### **Introduction**

A pilot scale permeable reactive barrier or treatment wall demonstration project was designed and constructed by the U.S. Navy Engineering Field Activity West at the former Naval Air Station (NAS) Moffett Field site in Mountain View, California about 2½ years ago. The Department of Defense (DoD) Environmental Security Technology Certification Program (ESTCP) has sponsored the Naval Facilities Engineering Service Center (NFESC) to validate the permeable reactive wall technology in remediating chlorinated hydrocarbon contaminated groundwater. Battelle Memorial Institute and PRC Environmental Management, Inc. (currently Tetra Tech EMI) were subsequently tasked by NFESC to develop and implement a Performance Monitoring Plan<sup>2</sup> for the permeable barrier project at Moffett Field. The Moffett Field barrier project uses a funnel-and-gate design, where the funnel is made of interlocking steel sheet piles and the gate consists of a reactive cell filled with zero-valent granular iron. Since its construction in April 1996, groundwater monitoring was conducted over a period of 6 quarters in an effort to demonstrate the effectiveness of the barrier technology in capturing and remediating groundwater that contained dissolved chlorinated hydrocarbon compounds. The primary contaminants of concern at Moffett Field in the vicinity

of the permeable reactive barrier are TCE, cis-1, 2 DCE, and PCE. Quarterly monitoring events have included water level measurements, field parameter testing, and groundwater sampling at approximately 70 observation wells or monitoring points. Two tracer injection tests using bromide solutions were also completed in April and August 1997 at the barrier site. Core samples of the iron cell were collected and analyzed in December 1997 by x-ray diffraction (XRD), Raman spectroscopy (RS), and scanning electron microscopy (SEM) methods. The coring sample results were then evaluated for reactivity and longevity characteristics by assessing the types of precipitates and corrosion compounds present in the iron cell. Data from the quarterly monitoring, tracer testing, and iron cell coring have been used to determine the overall barrier performance. This paper summarizes the results of the permeable reactive barrier technology demonstration project at Moffett Field.

The detailed results of this demonstration project will be distributed to various members of permeable reactive barrier technology working groups for their review and comment, such as the EPA Remediation Technologies Development Forum (RTDF) and the Interstate Technologies Regulatory Cooperation (ITRC), which includes regulators from about 29 states. The Moffett Field permeable reactive barrier final technology evaluation report is scheduled for public release at the end of August 1998, with the anticipation that this information can be used at several government and industrial contaminated sites worldwide.

## Technology Description

Research performed in the scientific community over the last 6 years, primarily at the University of Waterloo (Canada) and EnviroMetals Technologies, Inc. (ETI), has shown that when dissolved chlorinated solvents come into contact with zero-valent granular iron, the chlorinated compounds are degraded abiotically<sup>3</sup>. This chemical reaction occurs on the iron surface, which results in the reductive dehalogenation of the chlorinated hydrocarbons in the groundwater. Researchers have suggested that several different mechanisms are responsible<sup>4</sup>. Most familiar is the fundamental oxidation-reduction (redox) process of corrosion in which the iron is oxidized to form an aqueous ferrous species. An abiotic reaction occurs when the chlorinated compounds in the oxygenated groundwater come into contact with the iron, which is also referred to as the hydrogenolysis pathway. It is a relatively fast reaction and occurs in the first few inches of the iron medium. DCE and VC are formed as short-lived intermediates, which in turn rapidly degrade to ethanes and ethenes. The net effect is a release of ferrous iron, chloride ions, light hydrocarbons, and hydroxyl ions. The basic reaction is as follows:



The presence of the C2 to C5 light hydrocarbon byproducts indicates that the chlorine molecules are replaced with hydrogen in the reductive dechlorination process<sup>5</sup>. Other reactive mechanisms and combinations are also believed to exist. When dissolved oxygen is negligible and an anaerobic condition exists, the interaction of contaminated groundwater with iron granules causes the water to be reduced and form hydrogen gas. This process is referred to as the beta-elimination pathway, where alkynes are produced as short-term intermediates. Sorption may also play an important role in controlling the formation and release of degradation byproducts. Other important byproducts of the redox process are an elevated pH and a general increase in alkalinity. This can potentially cause chemical precipitates to form on the iron particles and can clog the reactive cell and reduce its treatment capacity<sup>6</sup>.

## Moffett Field Demonstration Project

A funnel-and-gate design configuration was used at Moffett Field, which is used to capture a larger portion of a plume and direct it towards a reactive iron cell. After bench-scale testing<sup>7</sup> and groundwater modeling<sup>8</sup> were completed, a 50-foot wide by 10-foot long by 25-foot deep permeable reactive wall funnel-and-gate system was installed across a contaminated portion of the chlorinated solvent plume at Moffett Field in April 1996. Forty-eight monitoring wells are present inside the gate and 21 wells outside (Figure 1.).

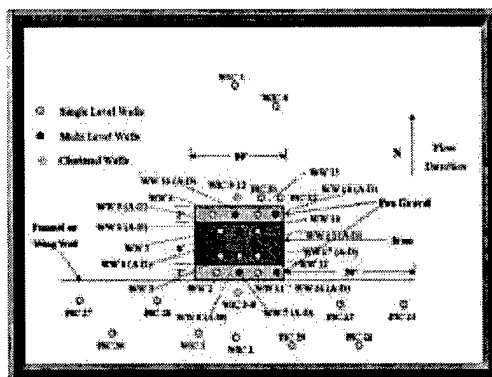


Figure 1. Funnel-and-Gate System at Moffett Field

## Performance Monitoring Objectives and Evaluation Criteria

The primary purpose of the Moffett Field demonstration project was to evaluate and verify the performance of a pilot-scale permeable reactive wall in remediating chlorinated hydrocarbons in groundwater. Eventually, it is anticipated that this technology can be used at several other Navy and Department of Defense contaminated sites. The following general objectives and technical performance criteria were used to evaluate the Moffett Field project.

Objective	Technical Performance Criteria
Evaluate the reactivity characteristics and the overall effectiveness of the permeable reactive barrier	<ul style="list-style-type: none"> <li>• Chlorinated solvent concentrations in the iron cell should be below MCLs or ND, compared to upgradient values.</li> <li>• Abiotic degradation byproducts should be observed in the reactive cell and in the downgradient pea gravel.</li> <li>• Flow, tracer, and slug tests in the barrier should indicate the desired residence time and flow through the iron cell.</li> <li>• Mass balance calculations of various parameters.</li> <li>• Iron cell corings may indicate if chemical or biological precipitates are forming and may inhibit reactive process.</li> </ul>
Evaluate the downgradient water quality	<ul style="list-style-type: none"> <li>• The permeable barrier should not allow any breakthrough of contaminants or introduce any sustainable levels of by-products into the aquifer above the MCLs.</li> </ul>
Evaluate the hydraulic capture efficiency	<ul style="list-style-type: none"> <li>• The capture zone should cover the portion of the plume targeted in the pilot-scale design, and be able to handle any seasonal water-level fluctuations or flow reversals.</li> </ul>
Estimate cost-effectiveness	<ul style="list-style-type: none"> <li>• The permeable wall design, construction, and O&amp;M should be a cost-effective alternative to pump-and-treat.</li> </ul>

Since the installation of the reactive barrier at Moffett Field, six sampling events have been performed. During the month of January 1997, continuous monitoring of redox potential (Eh), pH, temperature, precipitation, and water levels was conducted to evaluate the detailed changing conditions of the site relative to the permeable barrier. Slug tests, flow/velocity meter testing, and tracer tests were performed at the site from February to August 1997, to verify flow characteristics and that groundwater was actually flowing through the treatment cell (gate). Iron cell corings were also completed at several locations in December 1997.

## Monitoring Results and Conclusions

Based on the sampling results over the past 2 years, the performance of the Moffett Field permeable barrier has been rather impressive. These preliminary conclusions are derived from various portions of Battelle's contract deliverables and publications<sup>2</sup>. Further details on the Moffett Field reactive wall demonstration project can be found in these individual documents and the final technology

evaluation report.

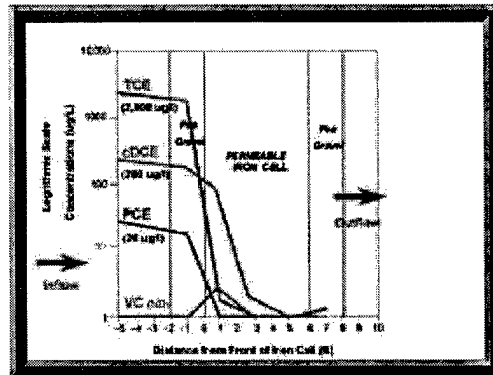


Figure 2. Quarterly Sampling Results for April 1997

- Each sampling event has indicated complete degradation of the chlorinated compounds in the iron cell. For example, in April 1997, upgradient groundwater concentrations of TCE (2,900 micrograms [ $\mu\text{g/L}$ ]), cis 1, 2 DCE (280  $\mu\text{g/L}$ ), and PCE (26  $\mu\text{g/L}$ ) were reduced to either below the drinking water maximum contaminant levels (MCLs) or to non-detect (ND) within the first 2 feet of the iron cell (Figure 2). Of particular significance, the chlorinated compound degradation product VC was ND in the upgradient aquifer wells. VC was slightly detected at 4  $\mu\text{g/L}$  in the first array of wells in the permeable cell, and suggesting that degradation was occurring. In the next array of downgradient wells within the treatment cell, VC was again ND, indicating its cleanup.
- Byproducts of the abiotic degradation ( $\text{Cl}^-$ ,  $\text{Fe}^{++}$ ) and light hydrocarbon gasses (methane, ethene, ethane, etc.) were observed in the iron cell, again suggesting the success of the chemical reaction. The pH rose to about 11 at some points in the reactive cell. Eh dropped to about -500 millivolts, indicating strong reducing conditions of the abiotic degradation. Eh and pH returned to their background values as the water exited the iron cell and mixed with the untreated aquifer water.
- Water level data immediately after barrier installation and during the rainy season (October 1996 to February 1997) indicated that mounding was present in the iron cell, which suggested a potential backflow condition may have occurred. After a couple of months, the water levels stabilized and returned to a natural forward flow gradient in the cell. This was later confirmed through continuous hydraulic measurements, flow velocity meters, and bromide tracer testing.
- Evaluations of the hydraulic water level measurements and flow meter testing results indicated that the actual capture zone of the funnel-and-gate system appeared to be only slightly smaller in reality than what was predicted by modeling. Water level gradients suggest a northerly forward flowpath through the iron cell at about 1.5 feet/day. Flow meter testing indicated a northeasterly direction at velocities of about 1.1 to 6 feet/day.
- Two tracer tests of the reactive barrier were initiated in April and August 1997. After injection of a bromide solution in the upgradient pea gravel and upgradient aquifer, it was detected in the iron cell along a linear pathway using continuous monitoring equipment. The estimated flow rate from these tracer tests was about 0.2 to 0.6 ft/day, which was somewhat less than the



modeled results (0.75 to 2.5 feet/day) and previous pump test results of about 1 to 4 ft/day<sup>10</sup>. With groundwater flow moving through the cell in a natural downgradient direction, and if backflow conditions ever existed, they were temporary in nature and occurred shortly after barrier installation. The average range of groundwater velocities in the reactive cell, after taking into account the limitations of various field measurements, may be estimated to be about 0.2 to 2.0 feet/day.

- Inorganic analytes exhibited distinct behaviors within the reactive cell and charge balance calculations performed on the inorganic data were of good quality (within 10% error). Redox sensitive ions such as nitrates and sulfates were also observed as being degraded along the flow path. Decreasing calcium and magnesium in the iron cell, along with increasing alkalinity and the relatively constant saturation index for calcite, may indicate the formation of precipitates.
- Iron cell coring results suggest early signs of the types of processes predicted for the iron-groundwater interactions, such as oxidation of the iron, reduction of the contaminants, precipitate formation, and the possibility of anaerobic microbial growth in the down-gradient aquifer. However, no obvious permeability or reactivity losses were apparent to date. The XRD, RS, and SEM results from the coring samples have indicated that less than 1% of the iron surface was covered with iron sulfide and calcium carbonate precipitate compounds. Using this information as a baseline, it is suggested that coring should be repeated after 5 years of barrier operation to evaluate the effect of precipitates on barrier performance.

The scientific community is researching the issue of longevity of the permeable reactive barrier technology. Presently, most users of the reactive barrier technology have attempted to address the concern of longevity by incorporating safety factors into the design, such as providing for extra iron cell thicknesses and widths or allowing for more granular iron surface area. In relative terms, one can readily estimate the construction costs of a barrier project, however, the longevity or maintenance costs would be more difficult to estimate at this time. ETI has suggested that maintenance costs can be assumed to equal a value of replacing 25% of the iron every 10 years. As the years pass and the technology advances, we expect the longevity or life expectancy to increase. In a best case scenario, the barrier could be left in the ground until the entire chlorinated solvent plume has been treated.

The demonstration results indicate that the cost of a permeable reactive barrier is closely linked to its selected design and construction method. Preliminary cost assessment estimates for implementing a full-scale reactive wall to remediate the 5,000-foot wide by 10,000-foot long chlorinated solvent plume at Moffett Field are approximately \$9 million over a 30-year period. By using the groundwater pump-and-treat remediation method at Moffett Field for the same time period, which includes a relatively large operation and maintenance budget, the estimated clean-up costs would be about \$33 million. Depending on any of a number of unique site factors, such as the nature and extent of the plume (size and depth) and the method of construction, the permeable reactive wall technology can be several times more cost effective than groundwater pump-and-treat.

Members of the RTDF and ITRC permeable barrier workgroups are encouraged and optimistic about the growing acceptance of the reactive barrier technology, as a viable means for remediating contaminated groundwater with chlorinated compounds. Presently, there are about 15 pilot and full-scale permeable reactive wall projects operating in the United States, with several more in the planning

stages. Permeable reactive barrier design guidance publications by Battelle<sup>11</sup> and the ITRC<sup>12</sup> have been developed as design protocol documents for use by site managers and regulators.

Further research is being conducted with permeable reactive barriers in using various construction deployment technologies for remediating deeper contamination and, also, in using bimetal combinations in the reactive cell. Copper, nickel, and palladium coated iron can potentially enhance the reaction rates, which allow for the use of thinner reactive cells.

## Notices

This report was prepared as an account of work sponsored by an agency of the U.S. Government. Neither the U.S. Government, any agency, any employee, nor any contractors and their employees make any warranties, expressed or implied, or assume any legal responsibility for the accuracy, completeness, or usefulness of any public or privately owned rights. Reference herein to any specific commercial product, process, service or trade name, trademark, or manufacturer does not constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency. The views and opinions of the authors expressed herein do not necessarily reflect those of the U.S. Government, its employees, or contractors. Upon further evaluation of additional data, the final evaluation report may result in modifications to the contents and conclusions of this report.

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# Site Characterization for Explosives Contamination at Military Firing Ranges

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## Abstract

Site characterization for explosives-contamination has been conducted at firing range impact areas in Canada and the United States. Unlike other explosives-contaminated areas, such as ammunition plants and explosives ordnance disposal areas, the contaminant present at highest concentration at firing ranges is generally HMX (1,3,5,7-tetrahydro-1,3,5,7-tetranitrotetrazocine). The presence of HMX on these ranges is a result of training with M72 Lightweight Anti-Armour Weapons (LAW). These rockets appear to have an abnormally high dud rate, and sometimes on impact, break open spilling solid explosives on the site. The LAW rockets contain octol, a melt cast explosive composed of a 70:30 mixture of HMX and TNT. The highest concentrations of HMX have been shown to reside in near-surface soils and the magnitude of contamination is related to the intensity of use of specific target areas. The areal distribution of HMX is correlated with target positions. The concentrations of TNT are much lower in these soils than would be expected, based on its percentage in the explosive mixture, except for very recent contamination. The largest problem associated with characterization of these firing ranges is the enormous spatial heterogeneity in concentration distribution that is present at all distances. Relative standard deviations greater than 100% are commonly encountered for samples collected only a meter apart. Thus concentrations measured from discrete soil samples are not representative of even small geographically defined areas. Colorimetric-based on-site methods for HMX and TNT have been shown to provide acceptably accurate and precise results for characterization at these firing ranges. However, neither colorimetric- nor immunoassay-based on-site methods are capable of providing accurate estimates for RDX, when HMX is present at an order of magnitude or greater concentration. Composite sampling and use of on-site methods has been shown to be effective means of characterizing these sites.

## Introduction

Over the past several years, the U.S. Defense Department has characterized the extent of explosive contamination at a large number of its installations. Contamination has been found to be substantial at government-owned contractor-operated ammunition plants and depots. Some of these facilities have produced military-grade explosives while others conducted load, assemble, and pack operations, with explosives supplied from production facilities. The source of contamination at depots was often the disposal of off-specification material, and the demilitarization of out-of-date munitions. In both cases, the contaminants most often observed were TNT (2,4,6-trinitrotoluene), RDX (1,3,5-hexahydro-1,3,5-trinitrotriazine), and their manufacturing impurities and environmental transformation products<sup>1</sup>.

Both laboratory and on-site methods have been developed to characterize the type of contamination found at ammunition plants and depots. The most commonly employed laboratory method is EPA SW-846 Method 8330<sup>2</sup>. This is an HPLC-UV method with 14 target analytes, including TNT, RDX, and HMX (1,3,5,7-octahydro-1,3,5,7-tetranitrotetrazocine). On-site methods have also been developed to characterize explosives-contaminated soils. The on-site methods that have had substantial validation fall into two categories: colorimetric-based and enzyme immunoassay-based methods<sup>3</sup>. These methods have targeted TNT and RDX, in particular. Recently, the colorimetric RDX method has been demonstrated to provide accurate characterization for HMX as well<sup>4,5</sup>.

A major problem with the characterization of contamination sources at explosives-contaminated sites is the high amount of spatial heterogeneity in explosive concentrations<sup>4-6</sup>. There are several reasons for this extreme spatial heterogeneity. First, explosives are solids at environmental temperatures, and secondly, they are deposited on the soil as particles. Hence they do not flow to equalize concentration. Rather, they stay where they were deposited until dissolved in aqueous solution. The rate of dissolution is slow for these compounds and therefore the surface soils at these sites can remain contaminated for decades.

Until recently very little attention has been given to residues of explosives at military firing ranges. There are several reasons for this lack of attention. First, it is thought that most of the explosives are destroyed during detonation, and hence little residues should remain. Secondly, these sites are known to have large numbers of unexploded ordnance, making site characterization both difficult and very dangerous. On the other hand, in Canada, many firing ranges were characterized recently in an effort to assess the environmental impact of this operational activity. Furthermore, many military facilities were closed both in Canada and the United States and some of these have firing ranges that need to be characterized prior to transferring the land to other uses. In general, low levels of multi-contamination by explosives were found on firing ranges, demonstrating that the detonation of ammunition is a relatively clean process which lead to a minimal impact on the environment. However, an exception was encountered at Canadian antitank firing ranges where high levels of HMX were founds in the surface soils.

## Objectives

The principal objective of the work described here was to characterize the concentrations of explosives residues at military firing ranges in the United States and Canada, where the munition fired was a melt cast explosive composed of a 70:30 mixture of HMX and TNT. In addition, we wanted to develop an innovative

strategy for characterizing these sites which generates near real time information from on-site analyses and overcomes the problem of large localized spatial heterogeneity in contaminant concentrations. An on-site colorimetric method, initially developed for RDX, was evaluated at two of the sites for estimating the concentrations of HMX in surface soils. Colorimetric and immunoassay based commercially available on-site methods for rapid determination of TNT were also evaluated and the results compared to that obtained using the standard laboratory method. To overcome problems due to spatial heterogeneity, a simple compositing approach was evaluated for obtaining representative samples within defined geographic boundaries.

## **Sites investigated**

Four explosives-contaminated installations were sampled. The first was an anti-tank range at the Canadian Force Base, Valcartier, Quebec (CFB-Valcartier)<sup>4</sup>. This is an active firing range where 66-mm M72 rockets filled with the melt-cast explosive octol (70% HMX : 30% TNT) have been fired on a routine basis for over 20 years.

The second installation sampled was the inland firing range at Fort Ord, California<sup>5</sup>. Firing ranges at Fort Ord were used until 1994. A wide variety of munitions were fired at the inland ranges, including M72 rockets and many other munitions, most frequently those containing Composition B, which is composed of TNT and RDX.

The third installation sampled was the Canadian Force Western Training Center Wainwright (WATC-Wainwright) where two ranges were sampled. Range 13 is the most heavily used firing range in Canada, and the main ammunition fired are 66-mm, 94-mm, and 105-mm M72 rockets. This is an active range and has been in operation since the Second World War. Range 22 was also sampled, but has been used to a lesser degree than Range 13.

The fourth installation sampled was Canadian Forces Ammunition Depot Dundurn (CFAD-Dundurn). There is the largest ammunition depot in Canada and has several active firing ranges, but these ranges have been used to a lesser degree since the Second World War. Two ranges were sampled, including one that hasn't been used for many years. Discussions will center on the work at CFB-Valcartier and Ft. Ord, but results from the work at WATC-Wainwright and CFAD-Dundurn will be mentioned with respect to similarities or differences observed.

## **Results and discussion**

### **Explosives residues detected at firing ranges**

Soil samples from all four installations were analyzed using SW-846 Method 8330. HMX was the residue detected at highest concentrations in all cases; maximum concentrations of HMX in surface soils were 2100 mg/kg, 587 mg/kg, 3700 mg/kg, and 120 mg/kg for CFB-Valcartier, Fort Ord, WATC-Wainwright, and CFAD-Dundurn, respectively (Table 1). A general correlation between the intensity/frequency of use of these ranges for firing can be established based on our results. Results from CFAD-Dundurn analysis indicate that a lesser degree of contamination (<120 mg/kg) is present; this correlates with a lower frequency of firing on these ranges in the past few years. Conversely, results for the most used anti-tank firing range in Canada, WATC-Wainwright, show a greater contamination, with HMX concentration as high as 3700 mg/kg.

**Table 1. Maximum concentrations of explosive analytes detected in soil samples from CFB-Valcartier, Fort Ord, WATC-Wainwright, and CFAD-Dundurn anti-tank firing ranges.**

<b>Compounds</b>	<b>CFB-Valcartier</b> Maximum concentration (mg/kg)	<b>Fort Ord</b> Maximum concentration (mg/kg)	<b>WATC Wainwright</b> Maximum concentration (mg/kg)	<b>CFAD Dundurn</b> Maximum concentration (mg/kg)
HMX	2100	587	3700	120
RDX	4.5	1.7	18	89
TNT	9.7	0.6	880	0.7
2-ADNT	14*	1.3	†	†
4-ADNT	14*	1.5	†	†
2,4-DNT	6.2	<d	2.1	<d
1,3,5-TNB	<d	<d	45	0.4

\* Concentrations of two isomers were not individually determined for CFB-Valcartier samples.

† Not adequately separated by liquid chromatographic analysis.

<d Concentration below method detection limits.

Other target analytes detected in soils from all four installations included RDX, TNT, and two environmental transformation products of TNT, 2-amino-4,6-dinitrotoluene (2-ADNT) and 4-amino-2,6-dinitrotoluene (4-ADNT). At CFB-Valcartier and WATC-Wainwright, we also detected 2,4-dinitrotoluene (2,4-DNT) in several soil samples, but this analyte was not detected in any of the 280 soil samples from Fort Ord, or in soil samples from CFAD-Dundurn. These analytes were generally present at sub-mg/kg levels, except in surface soils within a few meters of targets. At WATC-Wainwright, several soil samples had rather high concentrations of TNT (maximum detected was 880 mg/kg), but these soil samples were collected near ruptured munitions where the solid explosive had been spilled on the soil. In addition, two samples from CFAD-Dundurn had RDX concentrations of 85 mg/kg and 89 mg/kg, but these were the only samples at any of the four installations with RDX concentrations above 20 mg/kg. Detectable levels of 1,3,5-trinitrobenzene (TNB) were detected in several soil samples from WATC-Wainwright and CFAD-Dundurn. Concentrations of target analytes, other than HMX, even in surface soils near targets, were generally below 10 mg/kg.

It is interesting to note that the concentration of HMX was almost always several orders of magnitude higher than TNT in soil at all four installations<sup>4,5</sup>. This is surprising considering the initial ratio of HMX and TNT in the melt cast explosive Octol. Clearly, either there is an attenuation process in operation for TNT at these sites, thereby reducing its concentration relative to HMX, or TNT is more efficiently destroyed during detonations than is HMX, or both. We believe that TNT dissolves more rapidly in water and leaches into the soil profile, where it can be transformed and, perhaps, humified<sup>4,7</sup>.

### **Areal and vertical extent of contamination**

Concentrations of HMX in surface soils from all four installations were strongly correlated with the placement of targets. For example, Figure 1 presents the mean concentration of HMX relative to the placement of target tanks at CFB-Valcartier.

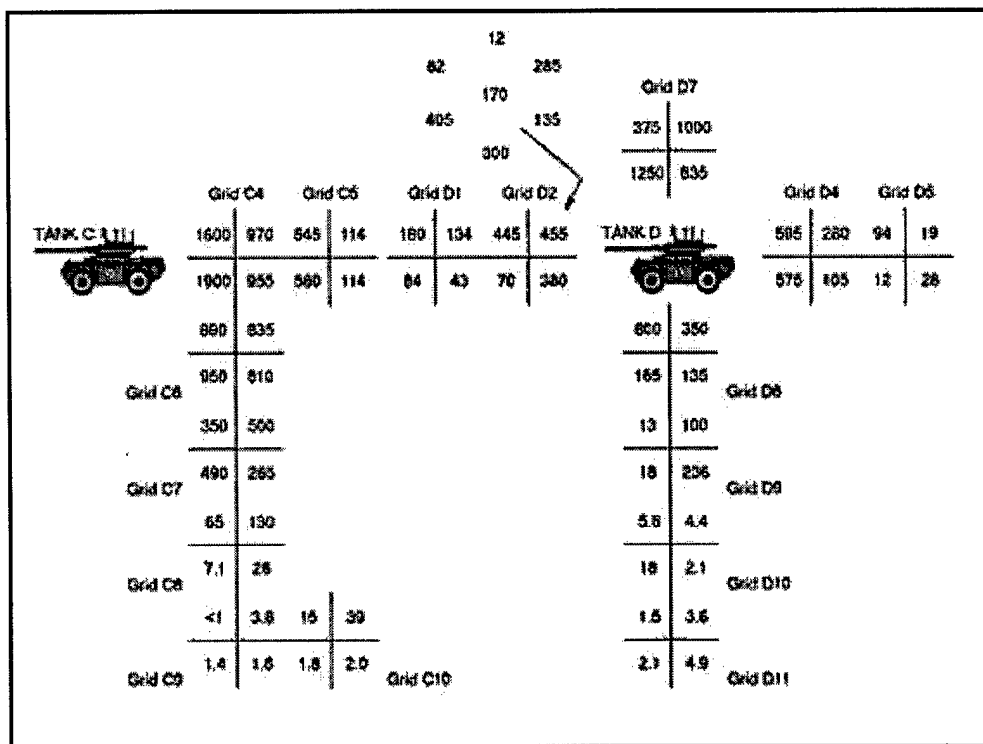


Figure 1. Concentrations of HMX (mg/kg) in surface soils at CFB-Valcartier, relative to positions of target tanks.

There was also a marked gradient in HMX concentrations in soil as a function of depth. At CFB-Valcartier, concentrations in the top 7.5 cm were at least 5 times greater than in soil from the 7.5-15 cm depth<sup>4</sup>. An even greater concentration gradient was found at Fort Ord<sup>5</sup>. For example, the mean concentrations of HMX in four soil profiles from a sampling grid next to a target location is shown in Figure 2.

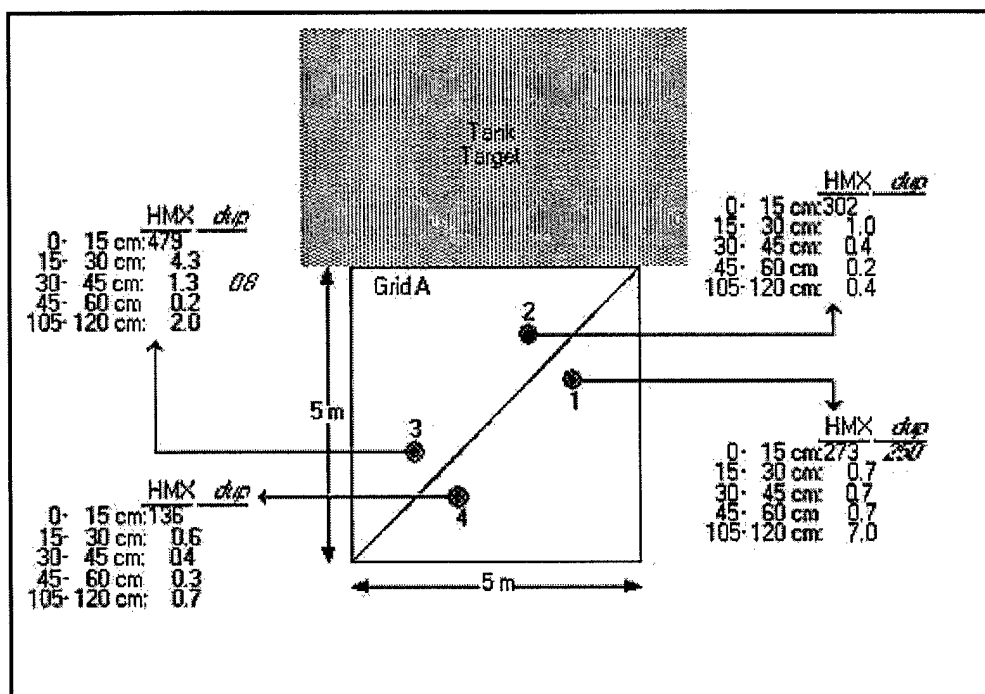


Figure 2. Concentration of HMX (mg/kg) as a function of depth for a sampling grid next to a target tank at Ft. Ord.

Concentrations of RDX, TNT, 2-ADNT and 4-ADNT in soils at all four areas were much lower than HMX. In general, these four analytes were only detectable in surface soils (0-15 cm depth). The concentrations of RDX and TNT in the surface soils at a heavily impact target area at Ft. Ord is shown in Figures 3 and 4, respectively. Overall, these findings demonstrate that the major residues of explosives at anti-tank firing ranges are present in surface soils, near target locations, and HMX is the contaminant present at highest concentration.

### Spatial heterogeneity

Spatial heterogeneity has been demonstrated to be a significant problem for site characterization at explosives-contaminated ammunition plants and depots<sup>6</sup>. At CFB-Valcartier, short-range heterogeneity was assessed by collecting seven discrete surface (0-15 cm) soil samples in a wheel pattern: a center sample and six samples around the circumference of a circle with a 122-cm diameter. HMX concentrations ranged from 12 mg/kg to 405 mg/kg with a mean  $\pm$  standard deviation of  $198 \pm 138$  mg/kg<sup>4</sup>. Any of these seven samples would be a legitimate discrete sample for characterization of this site according to a typical grid sampling plan, yet very different decisions regarding the need for remediation would be made depending on which of these samples happened to be collected. Characterization of these samples used two independent analytical methods, demonstrating that it was spatial heterogeneity, not poor analytical precision, which caused this variability. Because of this large spatial heterogeneity, it is estimated that sampling error is about 10 times the analytical error when these sites are characterized using discrete soil samples<sup>4,5</sup>.



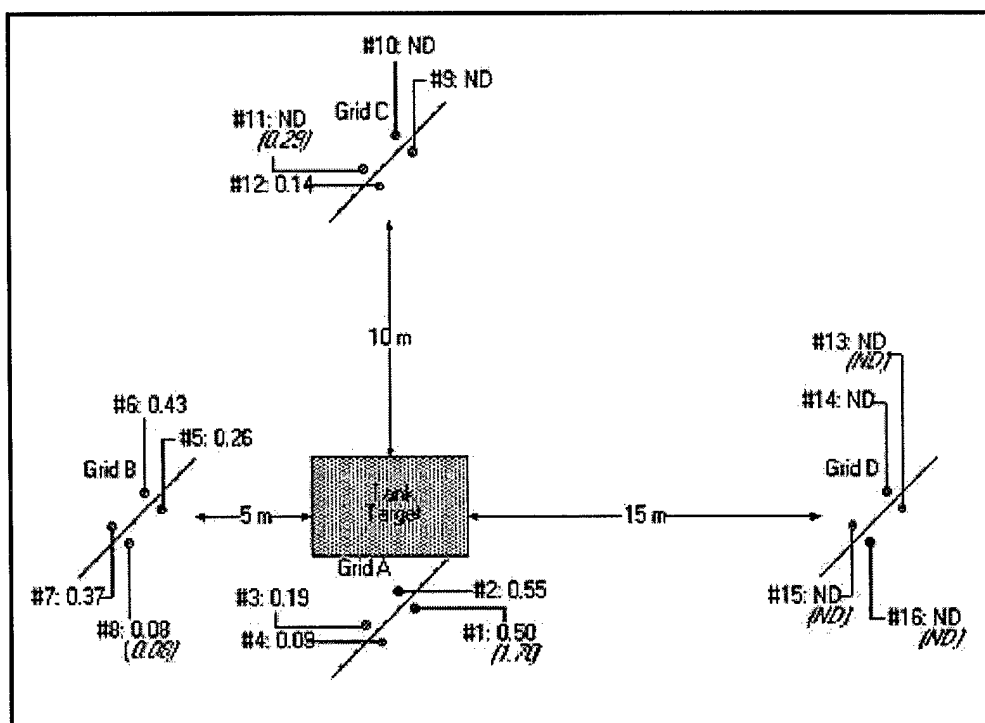


Figure 3. Areal distribution of RDX (mg/kg) in surface soils at a heavily impacted area at Ft. Ord.

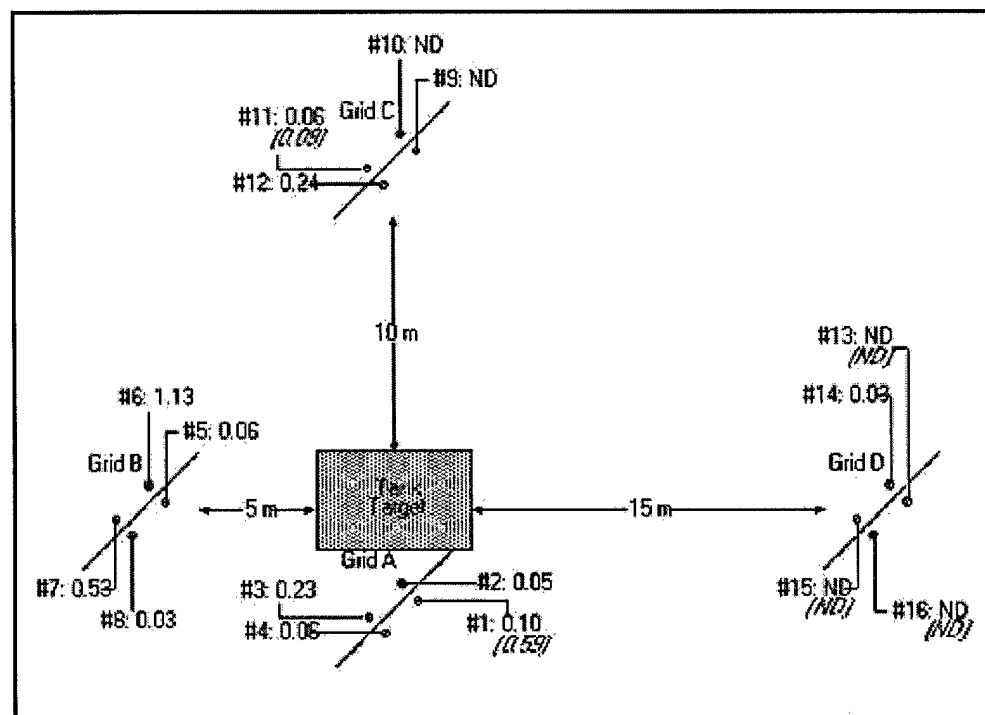


Figure 4. Areal distribution of TNT (mg/kg) in surface soils at a heavily impacted area at Ft. Ord.

At Fort Ord, spatial heterogeneity was assessed at several distance scales in areas with significant HMX contamination. Long-range spatial heterogeneity was evaluated using samples from different grids, and, as discussed above, concentrations of HMX were related to distance from targets<sup>5</sup>. Mid-scale

heterogeneity was assessed from individual discrete samples from within a grid. Relative standard deviations (RSDs) for the four samples from each of five depths varied from 48.1 to 122%, with a pooled RSD of 83.5%. Short-range heterogeneity was estimated from pairs of discrete samples collected 1 meter apart, and varied from 7.3 to 127%, with a pooled RSD of 71.8%. Very-short-range heterogeneity was estimated from split samples, and RSDs ranged from 1.6 to 99.7%, with a pooled RSD of 55.4%. For samples with concentrations above 10 mg/kg, the pooled RSD from split-sample analysis was 32%.

If site characterization at ranges is to provide reliable results, sampling and analysis plans must address the large uncertainty imposed by the large spatial heterogeneity that is present at all distance scales. Compositing of discrete samples has been shown to be effective at providing reliable estimates of mean concentrations for explosives-contaminated sites<sup>4-6</sup>.

### Utility of on-site methods

Soil samples from CFB-Valcartier and Fort Ord were analyzed using colorimetric-based on-site methods. An on-site method that was developed for RDX8 was found to be very effective at estimating HMX concentrations for these soils, relative to analysis of the same extracts by reversed-phase HPLC (Figure 5). Concentrations estimated from the on-site method was virtually identical to those from laboratory analysis of the same extracts. When comparisons were made with results from off-site laboratory analysis using independent extraction and analysis of separate subsamples, the results were nearly the identical, although the heterogeneity among different subsamples reduced the correlation coefficient from 0.983 to 0.971 and the slope from 1.01 to 0.988<sup>5</sup>.

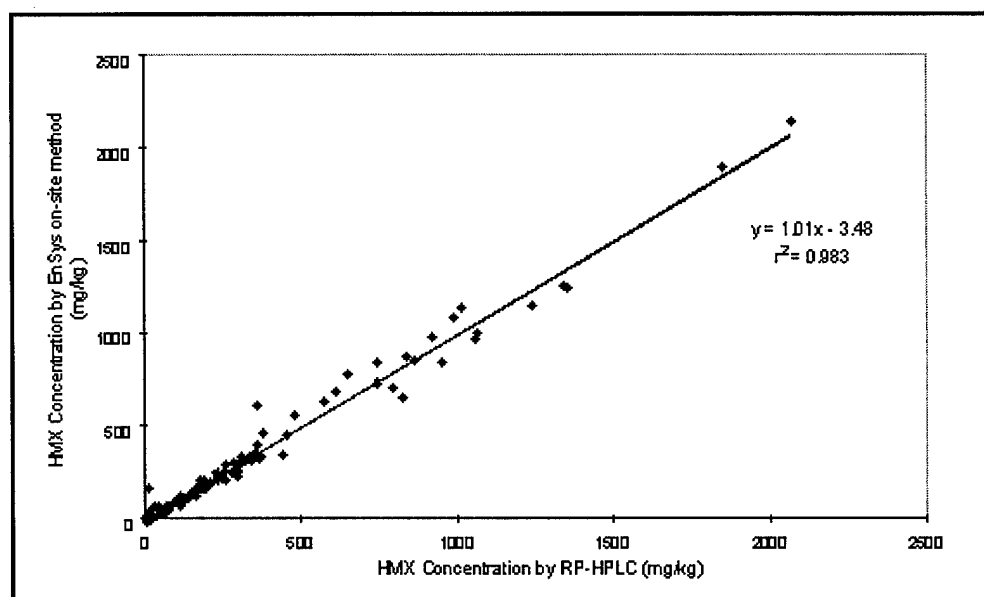


Figure 5. Correlation of HMX concentrations in extracts of surface soil samples from CFB-Valcartier and Fort Ord by EnSys colorimetric method and RP-HPLC.

Concentrations of TNT were much lower than HMX at CFB-Valcartier, and results from a colorimetric method for TNT from EnSys (now Strategic Diagnostics, Inc.) provided estimates for TNT in excellent agreement with those from HPLC analysis at a much lower cost<sup>4</sup> with a correlation coefficient of 0.983 and a slope of 1.05. Results using a commercial enzyme immunoassay on-site

method (DTECH, Strategic Diagnostics, Inc), were also acceptable relative to the sampling error introduced by spatial heterogeneity, however, a poorer correlation to the laboratory method was observed with a correlation coefficient of 0.906 and a slope of 0.69.

Unfortunately, however, neither the colorimetric on-site RDX method, nor an immunoassay-based RDX method (DTECH, Strategic Diagnostics, Inc), was capable of providing reliable low-concentration estimates for RDX, when HMX was present at much higher concentrations.

## Conclusions

Explosive contamination at anti-tank firing range impact areas was assessed and found to be substantially different from that found at army ammunition plants and depots. At firing ranges, HMX is the contaminant found at highest concentration in almost all cases. Contamination is strongly correlated with the locations of targets and the frequency of firing and is largely concentrated in surface soils. The spatial heterogeneity of analyte concentrations is very large and this factor most dominates strategies to obtain representative samples from these areas. We have found that a combination of homogenization of discrete samples, compositing, and on-site analysis using colorimetric-based methods is the most cost-effective way to provide adequate characterization for these explosives-contaminated sites.

We also demonstrated that the source of contamination on these ranges depend on the ammunition fired there, which has a high dud rate. This produces many broken casing that expose the melt-cast explosive Octol, which lead to soil and groundwater contamination by both HMX and TNT. This is a very important fact since recommendations to minimize this decremental impact in the future can be drafted. The best solution would consist in modifying the ammunition to overcome the non-detonation problem or to stop the firing exercises with this ammunition. On the other hand, collecting M72 duds produced after each firing practice, which would stop completely the leaching process and, therefore, the contamination. If this is not practicable, then Level one clearance should be conducted more frequently and, ideally, the contaminated soils should be remediated since a technology is now available<sup>9</sup> and has been demonstrated at CFB Valcartier<sup>10</sup>. Moreover, more data on the environmental fate of explosive in the environment are needed to better understand the relative fate of TNT and HMX in the environment.

## Acknowledgments

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# High Resolution 3D Seismic Reflection Surveys for Characterization of Hazardous Waste Sites

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Mark Kram

## Abstract

Under the aegis of the Environmental Security Technology Certification Program, high resolution three dimensional (3-D) seismic reflection data have been collected at four sites where Dense Non-Aqueous Phase Liquids (DNAPL) are believed to be present. Confirmation sampling and chemical analyses have been performed at two of these sites. The objectives of the seismic surveys were to delineate potential DNAPL fluid migration pathways and traps, and to potentially detect contaminant source zones directly, through DNAPL image recognition. The feasibility of using seismic attribute analyses to identify DNAPL source zones (directly and indirectly) has been evaluated at a site consisting of Karst topography and a site consisting of saturated silty sands and clay. Ground water and soil samples were collected from target locations identified by seismic attribute analyses. While additional confirmation work needs to be completed at a site consisting of interbedded sands and shales, and at a site containing intensely deformed fractured bedrock, results from the two sites discussed in this paper indicate that seismic attribute analysis is capable of identifying structural migration pathways in Karst topography. Migration pathway identification at the saturated silty sand and clay site was inconclusive. Direct detection of DNAPL source zones by seismic image recognition has not been substantiated by this effort thus far.

## Introduction

The Naval Facilities Engineering Service Center (NFESC) has been funded by the Environmental Security Technology Certification Program (ESTCP) to demonstrate and validate the use of high resolution, three dimensional (3D), seismic reflection surveys to support the identification and delineation of Dense Non-Aqueous-Phase Liquid (DNAPL) contaminant plumes. The objectives of this project are to evaluate the 3-D seismic reflection potential to delineate DNAPL fluid migration pathways and traps, and to determine whether the technique can be used to directly detect contaminant source zones using DNAPL image recognition at sites consisting of variable geologic materials.

The seismic reflection method is based on the principle that sound waves or acoustic signals will reflect from interfaces between layers in the subsurface. Lithologic changes produce reflections that make it possible to distinguish structure and stratigraphy. Vendor claims that subsurface DNAPL can attenuate propagating acoustic signals, and can therefore be directly detected, will also be evaluated under this investigation.

If this project is successful, the 3-D seismic reflection technique could significantly reduce the drilling and sampling requirements currently encountered under conventional site characterization and remedial investigations. Successful implementation has the potential to greatly decrease the costs and risks associated

with conventional characterization by optimizing the strategic location of monitoring and remediation wells.

## **Background**

DNAPL contamination sites present unique characterization and remediation challenges due to the physical properties of these materials. DNAPLs tend to migrate to relatively deep levels, often beyond the water table, due to their high specific gravity and low viscosity. DNAPLs also tend to move along preferential pathways such as faults, bedding planes, sand channels, and through relatively higher zones of permeability in complex porous materials. As they sink, they can leave behind a trail of microscopic globules or ganglia in the pore spaces of the soil matrix. When chlorinated DNAPLs reach the ground water, an immiscible "free product" phase can slowly dissolve into the ground water for decades to centuries. Even though the solubilities are low enough to allow the residual phase to persist for very long times, the solubilities are still high enough to render water concentrations many orders of magnitude greater than the current drinking water quality standards. Therefore, free phase DNAPL source zones need to be identified and completely characterized before successful remediation can begin<sup>1</sup>.

Lithologic heterogeneity and non-uniform DNAPL distribution can complicate source zone characterization and remediation approaches. The scale of the geologic variability that can influence DNAPL migration is generally smaller than can currently be characterized by conventional site characterization techniques<sup>2</sup>. While some direct-push techniques are beginning to show promise, conventional site characterization approaches including soil gas surveys and coincidental sampling are not reliable.

Current cleanup approaches include long term treatment of dissolved phase constituents, which is extremely costly (multi-million dollar ventures in many cases) and generally not very effective. The most popular approaches include pump-and-treat and cutoff-wall enclosures for containment of dissolved species assumed to be adjacent to DNAPL source zones. These approaches treat the symptom rather than the problem, because the source of dissolved constituents are the free phase DNAPLs. Due to equilibrium constraints, as dissolved constituents are removed via cleanup activities, free phase DNAPLs partition into the dissolved phase. These approaches often have large long-term costs, rely on partitioning kinetics, and can take many decades or longer to completely remove a plume<sup>2</sup>. Therefore, the need to identify the free phase DNAPL source zones located beneath the water table is critical to ultimately achieving site remediation.

## **Technology Description**

Seismic reflection is based upon the principle that if an impact is introduced at the surface, using a source such as a weight drop, acoustic waves will spread throughout the subsurface until they are reflected, or bounced back (to the surface), when material with a different acoustic impedance is encountered. Sensors, called geophones, located at the surface receive the impulses. A seismograph is used to record the data.

## **History**

Seismic reflection surveys have been performed in oil exploration to delineate the subsurface structure since the 1930's. While providing structural information, the technique yielded little data on the physical properties of the rocks (Savit and

Changsheng, 1982), forcing the oil exploration team to drill without an image (much as is done in environmental engineering today). As the use of seismic surveys became more accepted and as funds were available for research, the technique evolved so that it could provide subtle clues to structural and stratigraphic conditions that were missing or not discernable from other data, and provided effective ways to predict drastic structural changes with depth<sup>3</sup>.

By the 1970's, the oil industry had developed an interest in prospecting for shallow oil and gas traps, and developed the technique commonly called high resolution seismic reflection. The use of this technique required additional advances in instrumentation, which are now available and continually being improved.

According to Hunter<sup>4</sup>, where optimum conditions exist (including a fine grained or saturated overburden allowing recorded frequencies of 300 to 500 Hertz), structural resolution may be 1 meter. In other words, at depths of 100 feet or greater, it is possible to delineate features of a few feet or less in size. Therefore, at many sites it would be possible to characterize rather small subsurface changes in geology, and since DNAPL's prefer sand channels or faults as conduits as compared to clay or competent bedrock, it will be extremely useful to be able to locate these areas of preferred contaminant transport.

As early as the 1970's, oil companies made use of the fact that high intensity seismic reflections may be indicators of hydrocarbon reservoirs. Amplitude anomalies, or bright spots caused by nongaseous, abnormally high or low velocity layers, often have distinguishing characteristics<sup>5</sup>. Wang and Nur<sup>6</sup> have performed extensive experiments on changes in velocities that rock samples saturated with different hydrocarbon liquids exhibit. They have concluded that seismic properties of rocks containing hydrocarbon-filled pores are different than those with water-filled pores.

The development of seismic trace attributes analyses has allowed seismologists to quantify the amplitude, frequency and phase characteristics of each digital sample of the seismic traces. The instantaneous attribute of each sample can be calculated and displayed on a customized color scale. In this way, the trace attributes of contaminated and uncontaminated areas can be compared to try to determine whether the observed attribute anomalies may be due to structural or pore fluid contrasts.

## **Data Acquisition and Processing**

A high resolution 3-D seismic reflection survey consists of the following tasks.

- Site research/generation of a geologic model
- Vertical seismic profile
- Land survey
- 3-D seismic reflection survey
- 3-D data processing and interpretation
- Recommendations based on survey results

The development of a geologic conceptual site model is necessary to locate, optimize, and interpret the 3-D seismic survey. Development of the conceptual model consists of reviewing previous studies and reports that include site history, regional geology, tectonics, localized geologic descriptions, hydrology and surface contaminant release descriptions. When localized information is not available, the investigator must rely on regional information. For each site, a fracture trace analysis is performed using stereoscopic pairs of aerial photographs. All pertinent

information is compiled to generate the conceptual model of the site.

The information from the background research, photographs, and previously-collected physical samples is compiled to generate a model of the site. It is very important to the 3-D interpretation process that the background information and field geologic work has been completed, so that geologists understand what they are seeing in the seismic data. The development of a geologic model is necessary to optimally locate, focus, and to interpret the 3-D seismic survey.

A Vertical Seismic Profiles (VSP's) is used to measure velocity values, which are used to process the data and to define depth to geologic horizons. The VSP's are used to measure the actual near surface seismic velocities. This aids in the interpretation of the surface seismic lines. Stratigraphic information from the boring logs, along with one way travel times, provide the necessary data to correlate with the surface seismic lines.

The 3-D seismic grid is then designed, and locations for each receiver are flagged or spray painted on the ground surface. A land survey method is used to allow the placement of each grid station to sub-centimeter accuracy in X, Y, and Z positions. The seismic survey begins with a preliminary reflection, or noise, test. This test is conducted to determine the optimum filter settings, survey geometry, and the selection of optimum analog filters. The equipment shown below is used to collect the seismic reflection data.

Source	Sensors	Recorder	Ancillary Equipment
Elastic Wave Generator (EWG) 1.5; or Sledge Hammer	30 Hz Geophones Model SM-11	(3) 48 Channel IFP Seismographs	Geophone Spread Cables, with 6 takeouts per cable, bonding agent, flags, tape measure, vehicles

The 3-D seismic reflection survey is typically performed using three 48 channel seismographs (144 channels total). After the preliminary test line is processed and evaluated, the 3-D grid footprint is designed based on all the information generated.

The design of the survey is based on the size and depth of the features to be imaged, and the results of the noise test. Typically, 144 geophones are implanted at 20 foot grid spacings, using six lines each with 24 geophones per line. Three 48 channel seismographs are used to record the data. The 24 channel cables are connected directly to the seismographs, two per seismograph.

Once the geophones are in place, the source is impacted along lines offset from the receivers, focusing on the optimum window reflections from target depths. The distance of the impact lines from the receiver array is determined during the preliminary test. A sensor line and source line spacing of 20 feet allows accurate imaging of reflectors as shallow as 10 feet. The source is impacted at each station depending upon the offset, spacing, and parameters determined during the preliminary reflection test. A sufficient number of source impacts (6 to 16 impacts at each station) is used to record at least a 60 dB signal to noise ratio. The seismograph records and stores the data for each field record. After the data is collected, it is downloaded to tape.



Shown below is a seismic signal source, and an array of geophones connected to three seismographs.

*(not furnished)*

*(not furnished)*

Seismic Source

Seismographs and Geophones

The 3-D field data is stored in the seismograph in two separate hard drives. At the end of each day, the information is transferred to a PC. The PC is then used to convert the data from a compressed format to an oil industry standard format, Society of Exploration Geophysicists Format Y [SEG Y]. The SEG Y data is exported to a tape or a disc via a data port on the PC. The media is then shipped to the processor, to be processed and output on a 3-D SEG Y file.

This data processing is accomplished by sorting the field traces into bins. Bins are files that contain field traces with common reflecting points, re-arranging the data into true 3-D subsurface coverage. The binned data is then analyzed and bandpass filtered, Normal Move Out (NMO) corrected, stacked, migrated and output to a 3-D SEG Y file. The processing history for all seismic data is automatically compiled and available for listing, so that every process and process order for each seismic trace is fully documented. The 3-D SEG Y file is stacked and the output traces arranged in a 2-D grid, which will form a 3-D matrix of subsurface data. The amplitude data is analyzed to map coherent reflections, which is used to create 3-D perspectives of site features such as the competent bedrock surface and fractures.

The final output of the 3-D seismic data processing sequence is a SEG-Y file of the 3-D migrated trace data. In order to understand the hydraulic interconnections, structure, and stratigraphy, an interactive 3-D seismic analysis program is used to slice the site foot by foot. Pattern queries can be generated from east to west (lines), north to south (crosslines), from top to bottom (time slices), and along any other directions which are deemed to be of importance (arbitrary lines). It is also possible to read the traces, extract selected time values, and display a depth (or time) slice. The software can shade and display the traces in full color, allowing the subtle changes in the geology to be more easily viewed. The trace data is shaded, using a rainbow scheme, with very positive trace amplitude data shaded white, and very negative values shaded blue. Positive deflections in amplitude occur as the acoustic wave is reflected from the surface of a soft layer. Negative deflections in the amplitude occur as the acoustic wave is reflected from the surface of a hard layer. Hard and soft refer to the compressibility of a layer. Hard layers are less compressible than soft layers. Shown below is a seismic profile with some interpreted stratigraphic layers and faults called out.

*(not furnished)*

The interpreter may identify a horizon of interest (such as top of gravel, top of bedrock, etc.) and auto-track that horizon by virtue of cross-correlation. The process of cross-correlation can search for signals of similar character, from trace to trace throughout the site. An auto-tracker function and cross-correlation are used to create 3-D surfaces, which depict stratigraphic layers. Shown below is a 3-D representation of a top of bedrock surface based on seismic survey results, and a

photograph of the actual bedrock surface exposed nearby the survey site.

*(not furnished)*

*(not furnished)*

Top of Bedrock - Seismic Interpretation

Top of Bedrock - Actual

## Demonstration/Validation Effort

This project consists of demonstrating the ability to locate the subsurface regions of highest DNAPL contamination based on results from high resolution 3-D seismic reflection surveys. Subsurface targets are chosen at a seismic survey site based on the likelihood for the presence of DNAPL. The validity of these survey results are then evaluated through chemical analyses of groundwater and soil samples collected at target locations.

Four sites have been selected for this project in order to demonstrate the repeatability of these high resolution 3-D geophysical surveys under different conditions. Each of the sites has a well documented DNAPL problem. In addition, the four sites have differing geologic characteristics.

The geologic descriptors at the selected sites are listed below.

- Site 1 - Karst (limestone) topography
- Site 2 - unconsolidated marine silty sand and clay sediment
- Site 3 - interbedded sands and shales
- Site 4 - intensely deformed, fractured bedrock

## Project Status

The 3-D geophysical surveys have been completed at all four sites, and field validation of the survey results is currently underway. The field validation effort has been completed at Sites 1 and 2.

Nine DNAPL targets were identified for Site 1, of which three were fully investigated. Shown below is a seismic profile from the model generated for site 1, which includes DNAPL target #1. Also shown is the corresponding profile of the instantaneous amplitude, which results from an attribute analysis of the seismic signal intensity and essentially depicts the absolute value of the signal response. The DNAPL targets were chosen based on their potential for being located within preferential pathways or traps downgradient from a suspected surface contaminant source region, and having low seismic signal response anomalies associated with them.

*(not furnished)*

*(not furnished)*

Target #1 Seismic Profile

Target #1 Instantaneous Amplitude

Shown below are the instantaneous amplitude profiles for targets #2 and #3 at Site 1. The three wells completed during the investigation of these targets were capable of yielding large quantities of groundwater (up to several hundred gallons per minute). These wells were clearly completed within a highly permeable fractured zone or karst zone. Water samples collected at the first two targets had contaminant levels within the PPB (parts per billion) range, whereas dark globules of contamination were observed within the target #3 sample, both floating at the top of the sample container and resting upon sediments at the base of the container. Analysis of this sample indicated 3,000 ppm Volatile Organic Contaminants (VOCs), with TCE as the primary constituent. Seismic attribute contrasts between the target containing DNAPL and those considered false positives (light attribute shade, no DNAPL) were not identified. Therefore, the anomalies identified in the attribute analyses appear to be due mostly to structural contrasts and not chemical influences.

*(not furnished)*

*(not furnished)*

Target #2

Target #3

The targets identified at Site 2 were investigated with microwells installed with a direct-push technique. Hence, many targets were identified with the intention of collecting a large number of samples. Unfortunately, many of the targets could not be sampled due to accessibility constraints. Site 2 has a clay layer(s) which lies 15-45 feet below ground surface, above which all previous site characterization sampling has been conducted. Due to concerns for potential vertical migration of contaminants, sampling was not permitted beneath this feature. In addition, many of the shallow targets were located beneath man-made structures, making it impractical to sample them. Therefore, most of the higher rated targets identified by the seismic attribute analyses could not be sampled.

A total of 19 targets were sampled at Site 2. Of these, only 3 targets were situated above the clayey feature. All three of these samples had analytical results in the range of 10's of ppm dissolved phase constituents. The remaining 16 targets had contaminant levels in the non-detect to ppb range.

The presence of DNAPL at one region within Site 2 was identified by Laser Induced Fluorescence (LIF)<sup>1</sup>, visible identification of a non-aqueous phase beneath the water table using a video probe<sup>2</sup>, and confirmation sampling with analytical results as great as 4,000 ppm chlorinated VOCs. Although this region is located within the footprint of the seismic survey, the location of this particular investigative effort was selected based on a series of previous Navy Site Characterization and Analytical Penetrometer System (SCAPS) pushes. The nearest seismic target was located approximately 20 feet away, and had an analytical result in the 10's of ppm range.

Field validation efforts for Site 3 (interbedded sands and shales) and Site 4 (intensely deformed, fractured bedrock) are planned for October 1998. Seismic attribute analyses have been completed and field work plans are ready to be implemented.

## Discussion

Based on results from the validation efforts to date, it appears that 3-D seismic reflection surveys can help guide DNAPL characterization and remediation efforts by identification of preferential subsurface contaminant migration pathways. Identification of such pathways optimizes placement of monitoring and extraction wells. However, for the sites investigated under this project, the technology does not appear to be capable of directly detecting DNAPL. The anomalies identified using attribute analyses appear to be due solely to structural features, or each of the three wells completed at Site 1 would have encountered DNAPL. Despite these limitations, the successful target well exhibited a level of contamination that exceeded all previously measured levels at the site by at least an order of magnitude.

The results from the Site 2 validation efforts are somewhat inconclusive at this time. Although no significant contamination (>100 ppm dissolved phase constituents) was detected at the 19 targets investigated, accessibility to many of the higher rated targets was limited. Contaminant levels of moderate significance (10's of ppm) were found in 3 of the shallow (<20 ft. bgs) seismic targets identified.

Upon completion of field activities at the remaining two sites, a final report will be generated that will provide a comprehensive description of all field investigations and detailed results. This report should be completed by December 1998. At this time, the advantages and disadvantages of the approach to-date are summarized below.

Advantages of using the high resolution 3-D seismic reflection survey method for DNAPL source zone identification are listed as follows:

- Can collect seismic data in relatively non-invasive method.
- Can provide indication of structural migration pathways in competent geology;
- Can identify location of bedrock layers;
- Can save time and money by focusing intrusive efforts on structural migration pathways; and
- Can lead to a reduced number of wells and samples required for characterization and remediation.

Disadvantages of using the high resolution 3-D seismic survey method for DNAPL source zone identification are listed as follows:

- May not detect DNAPLs directly;
- Requires some intrusive "ground-truth" efforts to determine depths to targets;
- Requires weeks to months to process data and generate a confirmation work plan; and
- Data processing is subject to interpretation.

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# Evaluation of Retrofitting Existing Oil/Water Separators

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## Introduction

In order to maintain the operation readiness of tactical vehicles in the Department of the Army, it is necessary to perform frequent washing of the vehicles and their components. The wastewater generated by these washing activities typically flows to an oil/water separator. The oil/water separator serves as the primary pretreatment structure before being discharged to wastewater treatment plant. Effluent from those separators must comply with local, state and federal discharge quality limits.

The military is one of the largest owners of oil/water separators in the United States. The Army alone has thousands in operation. In recent years, it has become obvious that many of these separators cannot meet the necessary discharge limits. The poor performance of oil/water separators has promulgated DoD wide efforts to upgrade existing systems by replacing them or installing new systems in series with the existing oil/water separators.

## Vertical Tube Coalescers

AFL Industries Vertical Tube Coalescers (VTC) tube packs enhance the effectiveness of existing gravity oil/water separators. The tube packs provide a coalescing surface on which minute oil globules can agglomerate. The coalesced oil then rises to the water surface to be skimmed. The tube pack and optimization makes possible one of two goals or a compromise between them: 1) the oil content of the water can be sufficiently reduced to meet environmental regulations or 2) the flow through the separator can be increased without degradation of the oil separating performance.

The VTC tube packs are made of perforated polypropylene with oleophilic (oil attracting) properties. Suspended particles of oil agglomerate on the tube surface and migrate up. If the globules become sufficiently large and buoyant, the oil rises through the tubes. The vertical orientation of the coalescing tubes contributes to efficient separation.

With VTC, the oil is free to travel in a clear, upward path to the surface. This contrasts to plate pack designs, which may force the rising oil to move against the influent flow. A tube pack consists of modular, one-foot, welded bundles of VTC. Fiberglass channel and grating form a cradle to hold the modules in place. Eyebolts at the upper corners of the pack permit lifting of the entire unit for inspecting or servicing the separator.

Placing the custom-designed, oleophilic, polypropylene, vertical tube packs inside the gravity oil/water separator retrofits existing gravity systems. The channels then secure the tubes. The entire VTC tube pack is removable to minimize additional maintenance burdens.

## Bench Scale Testing

The U.S. Army Environmental Center sponsored an effort to examine retrofit technologies for existing oil/water separators on Army Installations. The primary technology examined is the use of VTC. The tubes were designed to be oleophilic to increase the effectiveness of existing oil/water separators.

The project consisted of a series of tests through the manufacturing of wastewater of several concentrations of oil and soil. Three influent concentrations of TPH and Total Suspended Solids (TSS) to the oil/water separator based on typical Army Reserve facilities wastewater characteristics determined by Mr. Gary Gerdes of U.S. Army Construction Engineering Research Laboratory (USACERL) (Gerdes, "Characterization of Oil/Water Separators at Army Reserve Facilities," Technical Report Draft, 1998.). Effluent from the oil/water separator was generated from the three different influent concentrations at four different flow rates. The effluent was analyzed for TPH and compared to the TPH influent.

This wastewater was then run through the oil/water separator to measure the oil content of the effluent. This was done with the coalescing tubes installed and removed. The tests were also run a variety of flow rates.

The wastewater influent and effluent were measured for oil concentration using EPA Method 1664: N-Hexane Extractable Material by Extraction and Gravimetry. This test yields Total Petroleum Hydrocarbon concentration and Oil and Grease concentration. The wastewater temperature was measured with a thermocouple to ensure consistency between tests. The consistent temperatures ensured that the separator performance was not influenced by temperature variations. The wastewater was also tested for pH to determine if acid cracking played a role in the separation process. Acid-cracking occurs when the pH of the wastewater falls below 2 which causes a dramatic increase of oil/water separation.

## **Results**

The VTC tested in the project improved the separation of oil out of the wastewater compared to situations without the tubes. In several instances the coalescing tubes were the difference between the effluent meeting the criteria for discharge into the sanitary sewer. The test data show that an average of 53 percent decrease in oil concentration in the effluent was realized using the coalescing tubes.

## **Lessons Learned**

When considering retrofit of existing oil/water separators, the existing oil/water separator must have three chambers for the coalescing tubes to be effective. The first chamber is for the settling of solids. The second chamber is for the removal of oil. The third chamber is for polishing the effluent. The third chamber should also have a weir to help separate the oil sheen from the effluent pipe. In addition the quantity of wastewater treated must be such that a wastewater velocity of 3 ft/min is not exceeded. Velocities above 3 ft/min will wash the oil from the coalescing tubes and into the effluent stream.

According to the manufacture of the coalescing tubes, the polypropylene tubes are susceptible to heat. This could have a profound effect on the removal capacity of the tubes in certain washing situations.

The amount of dirt in the wastewater has a detrimental effect on the ability of the coalescing tubes to attract oil. The tube's efficiency also increases the need for routine operation and maintenance. The increase in removal rate requires increase

frequency of sludge removal and oil disposal.

## Conclusion

The bench scale study of VTC demonstrated that they are an effective means to remove oil from wastewater. The significant decrease in oil concentrations in the effluent could aid the installation in meeting the discharge criteria of their waste streams. VTC will aid in the removal of oil but proper maintenance, design, and flow rate are critical to the effectiveness of the oil/water separator. Details of this study can be found in the U.S. Army Environmental Center report SFIM-AEC-ER-CR-98030 "Final Report of the Coalescing Tubes Test for Oil/Water Separators" (Klara 1998).

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# What if We Could Purify and Reuse Our Waste Aircraft Hydraulic Fluid?

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## Introduction

The United States Air Force (USAF) spends approximately \$30 million per year in the disposal and replacement of used hydraulic fluid. This estimate is based on Tyndall AFB consumption and disposal costs times the number of worldwide Air Force bases with flying missions. Most of this money could be saved if the hydraulic fluid were purified and reused. The Air Force Research Laboratory, Materials and Manufacturing Directorate, Airbase and Environmental Technology Division (AFRL/MLQ), Tyndall AFB, Florida, is sponsoring a project that will enable the Air Force to realize these savings.

Routine USAF aircraft operations generate large quantities of waste hydraulic fluid each year. Through regular use, accumulation of particulate matter and water requires the disposal of the fluid. The Air Force generated a need to evaluate economical equipment and/or processes that would allow the USAF to reuse the contaminated hydraulic fluid (USAF Environmental, Safety, and Occupational Health Need 95-530, Recycling and Verification of Hydraulic Fluid for Reuse). In response, AFRL/MLQ began a hydraulic fluid purification project.

Researchers chose to evaluate a portable hydraulic fluid purifier manufactured by Pall Aeropower Corporation. The Pall purification equipment was selected because it uses a vacuum dehydration, spinning disc process to remove water, air, and volatile organic solvents. It does not use desiccants, heat distillation, or high vacuum that could break down the properties of the base oil. It also incorporates a filtration system to remove particulate matter.

Initial testing revealed the Pall Purifier did not cause any adverse effects on the hydraulic fluid. However, continued testing was needed to evaluate the impact of using purified fluid in aircraft hydraulic pumps. The following text provides information on the testing to date.

## **Initial Evaluation**

In 1995, AFRL/MLQ evaluated the Pall purifier at Tyndall AFB, in an environmentally controlled facility. New hydraulic fluids from Velsicol Chemical Corporation, Castrol Specialty Products Division, and Royal Lubricants, and used hydraulic fluid from Moody AFB, Eglin AFB, and Dover AFB were evaluated. Each of the new hydraulic fluids was deliberately contaminated with measured amounts of deionized water (1200 ppm) and one gram of AC fine test dust (particulate) at hourly intervals. The Pall purifier was operated for a total of 18.5 hours, for each of the six hydraulic fluids evaluated. Three hydraulic fluid samples were collected from each of the fluids which included: unpurified (baseline), after 8 hours, and after 18.5 hours. The fluid samples were analyzed for degradation at the Materials Engineering Branch (MLSE) of AFRL, Wright-Patterson AFB, OH, in accordance with Military Specification MIL-H-83282C. The fluid was analyzed for viscosity, acid number, rubber swell, water content, lubricity (four-ball wear), evaporation, and oxidation-corrosion. The initial evaluation indicated that the Pall purifier did not degrade the fluids processed.

Based on these encouraging results, AFRL/MLSE recommended that wear testing be accomplished on aircraft hydraulic fluid pumps to determine the impact of fluid purification on pump life/performance. The F-16 emergency power unit (EPU) pump and the main hydraulic fluid pump were selected for these tests because they are common aircraft piston pumps and could be mounted on the test equipment. The Nonstructural Materials Branch (MLBT) of AFRL at Wright-Patterson AFB, OH was tasked to accomplish the tests.

## **Pump Wear Test #1**

The first pump wear test, sponsored by the B-2 Program Office, compared pump wear between two F-16 EPU pumps, operated under load, with both purified and unpurified MIL-H-5606F hydraulic fluid. The two pumps were operated for 1500 hours, each at 3000 psig, with flow rates cycled between 12 gpm and 3 gpm every minute. Each pump was then disassembled and inspected for wear. During the tests, fluid samples were extracted and evaluated for viscosity, water content, lubricity, foaming, metal content, and particle count. At the conclusion of the tests, there was no apparent difference in pump performance and no significant difference between fluid properties, with either purified or unpurified fluid. However, it was noted that there was an equal viscosity change in both the purified and unpurified fluids, which was attributed to the behavior of MIL-H-5606F hydraulic fluid and not the purification process. Again, the results encouraged further testing, this time with MIL-H-83282C hydraulic fluid.

## **Pump Wear Test #2**

The second pump wear test (in progress) is sponsored by the Ogden Air Logistics Center. The objective is to compare pump wear between aircraft pumps, operated under load, with both purified and unpurified MIL-H-83282C hydraulic fluid. However, each fluid will be intentionally contaminated with measured amounts (300 ppm) of distilled water. The two F-16 main hydraulic pumps will be operated for 2000 hours each, at 3100 psig, with flow rates cycled between 28 gpm and 6 gpm every minute. During the tests, fluid samples will be extracted and evaluated for viscosity, water content, lubricity, foaming, metal content, and particle count. Each pump will be disassembled and inspected for wear after 1000 hours and at test termination or 2000 hours, whichever comes first. The first phase of this test

using new hydraulic fluid began 4 Feb 98 and was terminated after 1262 hours because a temperature spike in the case drain flow caused an automatic shutdown of the equipment. Pump teardown revealed spalling on the inner race of the roller bearing and the rollers. Excessive wear was also observed on the outer diameter of the cylinder block. Preparations for the second phase of this test are underway using purified hydraulic fluid. The estimated completion date is December 1998.

## Operational Utility Evaluation

Headquarters Air Mobility Command (HQ AMC) is currently conducting an operational utility evaluation at McChord AFB, WA on a purifier provided by Pall Aeropower Corporation. This purifier incorporates a state-of-the-art water sensor that automatically shuts off the equipment after a preset level of cleanliness has been reached. HQ AMC plans to determine if the purifier is capable of sufficiently cleaning hydraulic fluid without degrading fluid characteristics and determine if the purifier is logistically supportable. This will be accomplished by purifying new MIL-H-5606, MIL-H-83282, and MIL-H-87257 that has been contaminated with measured amounts of AC fine test dust, deionized water, and PD-680 (solvent). They will also validate procedures to connect the Pall unit to a portable hydraulic test stand, an in-shop hydraulic test stand, and C-141 aircraft hydraulic systems. The estimated completion date is September 1998.

## Conclusion

It is widely recognized that water and particulate contamination can degrade critical physical properties of hydraulic fluid, impair pump performance, and cause premature failure of the pump. By removing the water and particulates through filtration and purification, users can reuse the hydraulic fluid. The results of the initial evaluation and Pump Wear Test #1 should encourage consumers of large quantities of hydraulic fluid to consider purifying contaminated hydraulic fluid for reuse instead of immediate disposal. **Note:** Hydraulic fluid contaminated with other oils or fuel cannot be purified and reused through this process because it will not separate them.

Commands and Air Logistics Centers wanting to save money could benefit by extending the service life of hydraulic fluid without degrading the fluid's working properties. The average Air Force base can expect to invest less than \$50K to reap full benefits of this process, which can be expected to reduce waste hydraulic fluid by 75 percent. The estimated annual Air Force savings of \$30 million from use of this process can be multiplied several times, if the process is extended to the Department of Defense and the private sector. This is a truly transferable technology.

It should be noted that the U.S. Army has approved the use of purified MIL-H-46170 and MIL-H-6083 hydraulic fluid in their ground systems. For further information contact Mr. Ralph B. Mowery, AMSTA-TR-D/210, U.S. Army Tank Automotive & Armaments Command, Warren, MI 48937-5000. His telephone number is (810) 574-4220. The AFRL/MLQ points of contact are Captain Gus M. Fadel, Tyndall AFB, Florida, DSN 523-6462 or (850) 283-6462, or Mr. Edward B. Seaman, TRW, DSN 523-6290 or (850) 283-6290.

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# Combining Natural Attenuation and Site-specific Remediation Goals for Site Closure

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## Overview

The Air Force is responsible for thousands of sites throughout the United States and abroad that are contaminated with petroleum hydrocarbons such as jet fuel, diesel fuel, gasoline, and heating oil. Despite significant improvements in fuels management over the past 20 years, equipment failures and human error will continue to create new spills which may require remediation. During the past five years, positive regulatory changes have taken place as the United States Environmental Protection Agency (USEPA) and a majority of state regulatory agencies have adopted more flexible, risk-based regulations for petroleum release sites. In addition, many states now recognize natural attenuation as a viable treatment alternative for petroleum-contaminated groundwater.

The remediation approach described in this paper is "risk-based" because it focuses on reducing unacceptable risks at contaminated sites. The Air Force Center for Environmental Excellence (AFCEE) has sponsored several risk-based site remediation demonstrations to illustrate how various combinations of land use control, site-specific risk analysis, natural attenuation, and focused source reduction technologies have been used to obtain risk-based site closures agreements at Air Force sites across the United States. In an effort to reduce the cost and time of cleaning up fuel-contaminated sites, AFCEE has developed a streamlined remediation approach that is comprised of five key elements:

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- Maximum Use of Land Use Controls To Eliminate Potential Exposure
- Promotion of Chemical-Specific Cleanup Standards
- Improved Site Characterization Methods
- Scientific Documentation of Natural Attenuation, and
- Cost-Effective Technologies for Contaminant Source Reduction

The coordinated use of these tools will result in more achievable cleanup goals and the maximum use of natural attenuation, bioventing, and other cost-effective cleanup techniques. There are several benefits associated with the use of a risk-based remediation approach:

- A focus on only those contaminants that pose a potential risk to human or ecological receptors. The premise of risk-based remediation is that the

decision to remediate any petroleum release site should be based on the actual or potential risk posed by site-specific contaminants to human and ecological receptors. This is an intentional move away from the use of cleanup standards for total petroleum hydrocarbons (TPH), which is not the true "risk driver" at petroleum release sites.

- More flexible and realistic cleanup standards based on actual land use (which on most bases is commercial or industrial) rather than conservative "residential" scenarios. Flexibility is available to choose between a more rapid and costly remediation, which will allow more immediate, unrestricted land use, and a less expensive natural attenuation option, which requires some long-term restrictions on land and groundwater use.
- A streamlined process. The Air Force risk-based remediation process is designed to integrate the site investigation, risk analysis, and feasibility study into a single effort, rather than conducting each of these in separate phases. Several risk-based site demonstrations, including two large petroleum, oil, and lubricant (POL) tank farm facilities, have progressed from site investigation to an approved site closure agreements in a period of less than 3 years.
- Significant cost and time savings have been demonstrated at Air Force sites which have entered into risk-based site closure agreements. Cost savings of 40 to 60 percent have been realized when compared to the more traditional Installation Restoration Program process of site investigation, risk assessment, feasibility study, remedial design and remedial action. Typical timeframes for completing the standard IRP process have ranged from 5 to 7 years at a cost of \$500,000-\$700,000 for a typical Air Force gasoline station or JP-4 pumphouse to obtain a site closure agreement. Using the risk-based approach, costs of \$200,000 to \$300,000 have been consistently demonstrated in project timeframes of less than 3 years.

## Example Case Study

Parsons Engineering Science, Inc. (Parsons ES) was retained by the United States (US) Air Force Center for Environmental Excellence (AFCEE) to prepare a corrective action plan (CAP) in support of a risk-based remediation decision for soil and groundwater contaminated with fuel hydrocarbons and nonfuel organic compounds at Site ST-27 at Charleston Air Force base (AFB), South Carolina. Site ST-27 consists of several underground storage tanks (USTs) used to store JP-8 jet fuel, motor gasoline (MOGAS), and diesel fuel to support aircraft operations at the base. One or more fuel releases from leaking USTs and fuel transfer lines have contaminated site soil and groundwater with fuel hydrocarbons.

The purpose of the CAP was to document the reasonable potential risks to human health and the environment (i.e., ecological receptors) due to exposure to chemical contaminants originating from Site ST-27 under current conditions. The CAP also estimated the potential risks to future human and ecological receptors due to exposure to chemical contaminants over time, accounting for the effects of natural chemical attenuation processes. Finally, the CAP developed and described a recommended remedial approach for fuel hydrocarbon and nonfuel organic contamination in soils and groundwater at and downgradient from Site ST-27 in accordance with the requirements of the South Carolina Department of Health and Environmental Control (SCDHEC).

The CAP provided the documentation elements specified by the Underground

Storage Tank Program of the South Carolina Department of Health and Environmental Control (SCDHEC, 1995) for both Tier 1 and Tier 2 risk-based assessments and evaluations. The SCDHEC guidance outlines a tiered approach for establishing corrective action requirements at specific sites based on an evaluation of potential exposures to chemical contamination at or migrating from a release site. Per SCDHEC regulations, once a release has been initially classified, the site should be subject to a Tier 1 evaluation. A Tier 1 evaluation is essentially a screening-level assessment where contaminant concentrations measured in site media are compared to nonsite-specific (i.e., generic) values. The RBSLs were used to identify which, if any, contaminants and environmental media may warrant additional evaluation or remediation. If measured site concentrations do not exceed the applicable Tier 1 criteria, no additional remedial actions would be required by the SCDHEC. However, it would be necessary to maintain land use in accordance with the exposure assumptions used to derive the cleanup goals.

In the event that measured site concentrations exceed the applicable Tier 1 RBSLs, a Tier 2 evaluation may be pursued. A Tier 2 evaluation is more comprehensive than a Tier 1 analysis because it requires quantitative contaminant fate and transport calculations and the development of site-specific remediation goals for potential receptor exposure pathways based on reasonable exposure assumptions and actual land use considerations. Tier 2 site-specific target levels (SSTLs) are based on the outcome of a predictive exposure pathways analysis to evaluate current and potential future human health risks and short-term and long-term fate of the contaminants at the site. Tier 2 evaluations usually involve more rigorous analysis and may require use of institutional controls to ensure that exposure conditions do not change over time. A cleanup based on a Tier 2 evaluation should result in a more focused remediation of those contaminants that may actually pose a risk to potential receptors (SCDHEC, 1995).

### **Defining Site Characterization Data Requirements**

In order to make a credible and defensible RBCA decision for this site, adequate and appropriate site characterization data must be available. Sufficient data had to be collected to conduct a quantitative fate and transport analysis, perform an exposure pathways analysis and limited risk-assessment, and evaluate the potential treatability of contaminated media using low-cost remedial technologies and approaches. As part of the risk-based investigation at Site ST-27, emphasis was placed on filling data gaps identified during previous investigations and on collecting data relevant to documenting the in situ biodegradation of fuel hydrocarbons in soil and groundwater.

After a review of previously collected site data, data gaps and target analytes were identified. Data gaps were determined by reviewing a preliminary conceptual site model (CSM) to identify previously undefined potential contaminant migration pathways. Target analytes were identified based on the chemical constituents of the known contaminant sources (JP-4, JP-8, diesel fuel, and MOGAS), and on the results of previous sampling activities at the site. The BTEX compounds, 1,2,4-trimethylbenzene (1,2,4-TMB) and 1,3,5-trimethylbenzene (1,3,5-TMB), naphthalene, and chlorobenzene were identified as target analytes. Additionally, analyses were performed for various SVOCs and other polynuclear aromatic hydrocarbons (PAHs) to determine the concentrations of these compounds in soils and groundwater at the site. To validate and implement a risk-based remedial approach at Site ST-27, additional data were collected to: (1) establish groundwater flow characteristics, groundwater and soil geochemistry, and aquifer parameters; (2) identify all possible sources that may be contributing to groundwater contamination at the site; (3) evaluate the potential for contaminant source areas to degrade groundwater quality; and (4) identify potential

contaminant receptors.

## Site Investigation

The following sampling and testing activities were performed at Site ST-27:

- Installation of 9 additional groundwater monitoring wells, including 2 wells screened at different depths, 1 air sparging test well, and 8 new shallow VMPs;
- Collection of 30 subsurface soil samples for laboratory analyses from 15 of the boreholes drilled for the installation of new monitoring wells, the air sparging well, and VMPs;
- Collection of 30 groundwater samples from a total of 22 groundwater monitoring wells, including 13 previously installed wells and the 9 new monitoring wells installed by Parsons ES;
- Collection of three SUMMA® canister soil gas samples for quantitative laboratory analyses from three soil VMPs located in close proximity to the suspected fuel source area;
- Collection of 2 samples of "free-phase," mobile LNAPL fuel product from 2 wells for laboratory analyses of fuel composition;
- Using portable field instruments, measurement of soil gas parameters of oxygen (O<sub>2</sub>), carbon dioxide (CO<sub>2</sub>), and TVH from 6 of the 8 new VMPs (2 of the VMPs contained water on the date of the field measurements); and
- Performance of aquifer slug tests on 10 wells to determine the hydraulic conductivity of shallow and deep zones of the surficial (water table) aquifer.

In addition to these recent field activities, ES (1993) previously conducted a bioventing pilot test at Site ST-27 in May 1993. Field testing, sampling and data collection activities performed during the bioventing study that are relevant to this risk-based remediation study include the following:

- Performance of a limited soil gas survey using seven temporary VMPs to determine soil gas composition for O<sub>2</sub>, CO<sub>2</sub>, and TVH;
- Installation of 4 permanent VMPs (including a background point) and 1 vertical air injection VW;
- Collection of 3 subsurface soil samples for laboratory analyses from boreholes installed for the VMPs and the VW;
- Collection of 3 SUMMA® canister soil gas samples from 3 different VMPs for fixed-base laboratory analyses;
- Performance of soil air permeability tests and initial in situ biorespiration tests.

## Source Reduction Technology Testing

Two potentially appropriate engineered source-reduction technologies were identified for this site: soil vapor extraction (SVE) and *in situ* bioventing.

Parsons ES conducted a bioventing pilot test at Site ST-27 in May 1993 as part of a separate AFCEE remedial technology testing program. Initial pilot testing indicated that bioventing would be effective in remediating petroleum hydrocarbon contamination in shallow, unsaturated soils at Site ST-27. Based on oxygen utilization rates, an estimated 160 to 1,150 mg of fuel per kg of soil can be degraded each year at this site. Additionally, a recent pilot tests at other Charleston AFB sites indicate bioventing is highly effective in reducing BTEX contamination in unsaturated soils.

An SVE pilot test utilizing a horizontal vapor recovery trench and an internal combustion engine (ICE) to treat vapor emissions was initiated in January 1996. The SVE test was run for six months to evaluate the feasibility of removing VOCs and reducing the contaminant mass in the source area using this technology. Significant decreases in total volatile hydrocarbons (TVH) occurred at all vapor monitoring points (VMPs). Based on the results of the initial test, the radius of influence of the single vapor recovery trench was conservatively estimated at 50 feet. However, the radius of vacuum influence was not uniform in all directions due to interrupted flow paths caused by buried tanks and pipelines. To insure that all contaminated soil could be effectively treated, a second horizontal vapor recovery trench was installed at the site in August 1996. The SVE pilot system was operated between February 1996 and May 1997 as an interim action to remediate the elevated levels of VOCs in soil gas. The results of the SVE interim action are discussed later in the case study.

### **Present and Future Land Use Information**

During the field investigation at the base, current and future land use information was collected to determine which generic, land-use based, Tier I screening criteria (i.e., RBSL) would be appropriate for the site. Site ST-27 is located in the north-central portion of the base adjacent to Building 575. The entire extent of Site ST-27 and the adjacent SWMUs is within the boundaries of the base, which is surrounded by a chainlink fence. The base is under manned guard 24 hours per day, 7 days per week. The site is located within a designated aircraft maintenance area. Access to this area is restricted. Additionally, the site is capped by 8 to 14 inches of concrete, which precludes direct exposure of base workers to impacted soils and groundwater.

Most of the area surrounding Site ST-27 and adjacent SWMUs comprises the base industrial aircraft operations and maintenance facilities. This industrial land use supports aircraft maintenance hangars, component repair shops, squadron operations buildings, base operations, a passenger terminal, and an air freight terminal. The base is active and is not on any known US Department of Defense closure lists. Future land use changes for some portions of the base are being considered; however, according to the base master plan, the area of Site ST-27 and adjacent SWMUs remain designated as part of the aircraft maintenance and operation facilities. After UST system decommissioning in 1997, it is expected that the land use at and immediately surrounding Site ST-27 will remain industrial.

### **Groundwater and Surface Water Use Information**

Groundwater within the vicinity of Charleston AFB is used for both industrial and domestic supply purposes. The closest known domestic well is located approximately 2.2 miles downgradient (southwest) from Site ST-27, approximately 1.2 miles downgradient from the southwestern boundary of Charleston AFB. Domestic uses of local deep groundwater resources include heat pumps and lawn and garden irrigation.

### **Ecological Resources**

At Site ST-27, the concrete cover and activity level associated with aircraft maintenance in this generally heavily-developed area effectively limit the presence of wildlife populations to the occasional song bird. The only vegetated areas present are two grassy areas covered with maintained grass and forb communities. These areas do not support trees, and the root zone likely does not extend to the water table. The low structural diversity, the surrounding industrial development,



and the managed character of these vegetated area likely limit their attractiveness to wildlife.

## **Tier 1 Screening Evaluation**

A Tier 1 screening analysis involves comparing the site-specific contaminant levels to generic levels developed using conservative assumptions. Only those chemicals with contaminant levels above the Tier 1 RBSLs will be subject to further evaluation and potentially to remedial action. After sufficient analytical data and other relevant information were collected, a Tier 1 screening evaluation was performed for Site ST-27 to identify chemicals of potential concern (COPCs).

Tier 1 groundwater RBSLs were compared to the maximum detected site chemical concentrations in groundwater, and those chemicals with concentrations above the RBSLs were identified as COPCs. Note that the Tier 1 analysis and conclusions conservatively considered and addressed the possibility of future unrestricted use of groundwater resources (i.e., unrestricted groundwater use will be assumed for the surrounding off-base and downgradient areas). For ambient air exposures, the Tier 1 analysis only examined the BTEX compounds. The SCDHEC guidance does not provide ambient air RBSLs for PAHs, stating that these compounds are not a concern due to their low volatility. Those chemicals with maximum site concentrations above the RBSLs were identified as COPCs.

Benzene, toluene, ethylbenzene, xylene, naphthalene, chlorobenzene, and 1,3,5-TMB were identified as the site COPCs in soil. These analytes were present in soils at concentrations high enough to potentially cause an exceedance of groundwater RBSLs through soil leaching. It is important to emphasize that soil concentrations did not exceed the RBSLs for ingestion of, or dermal contact with, soils under either a commercial or industrial scenario.

Benzene, toluene, ethylbenzene, naphthalene, chlorobenzene, 1,2,4-TMB, 1,3,5-TMB, and *cis*-1,2-dichloroethene (*cis*-DCE) were identified as the groundwater COPCs. All of these except *cis*-DCE are fuel-related compounds thought to be directly associated with releases at Site ST-27. The compound *cis*-DCE is considered a COPC, although its source is not related to Site ST-27.

All BTEX compounds identified in soil gas are potential ambient air COPCs. In addition to being identified as potential COPCs, the concentrations of the BTEX compounds found in soil gas samples, could potentially represent an explosive hazard to Building 575 or subsurface utility systems. The potential explosion hazard was reduced through installation and operation of a soil vapor extraction (SVE) system.

## **Tier 2 Analysis and Identification of Chemicals of Concern**

Chemicals identified as COPCs during the Tier 1 process should not automatically be considered to be present at levels that pose unacceptable threats to human health. Rather, these exceedances of the screening criteria indicate that further evaluation under more site-specific exposure scenarios is warranted. This second phase of evaluation is described as a Tier 2 evaluation (SCDHEC, 1995) and consists of three steps: 1) establishing site-specific exposure points; 2) establishing site-specific points of compliance (or, as is the case for Site ST-27, points of action (POAs)); and 3) calculating the corresponding site-specific concentrations for the COPCs at the POAs and in the source area, based on the measured and predicted

attenuation of the COPCs. As part of the Tier 2 analysis, exposure pathway completion was reexamined to identify only those receptors and exposure pathways that realistically may be completed under actual current or hypothetical future exposure scenarios, considering land uses and the results of the chemical fate and transport assessment.

## **Nature and Extent of COPCs**

The nature and extent of compounds identified as COPCs was evaluated using previous site investigation data and the data collected during the 1995/1996 risk-based site investigation. It was found that soil contamination at Site ST-27 is predominantly within saturated soils underlying the former location of the 3,000 gallon JP-4 jet fuel UST and the current location of the MOGAS and diesel USTs. Dissolved contamination currently appears to impact an area of less than 2 acres within the immediate vicinity of the fueling dispenser island and canopy on the north side of Building 575. Although recent site data imply a southwesterly groundwater flow (and contaminant transport) direction, historical water table level measurements and compound-specific analytical data suggest that multi-directional groundwater flow may occur at the site. A comparison of compound-specific data at specific sampling locations over time shows that groundwater COPC concentrations are decreasing and the plume is relatively stable.

## **Contaminant Fate and Transport**

Modeling was performed to predict how COPCs may be transported and transformed over time in LNAPL, soil, and groundwater based on site data and simple mathematical solute transport calculations. This modeling assumed no engineered remedial action is undertaken at Site ST-27. The behavior of COPCs under the influence of natural physical, chemical, and biological processes was quantified to predict: 1) the extent that soil COPCs could leach from contaminated soils and LNAPL into underlying groundwater; 2) to assess the expected persistence, mass, concentration, and toxicity of dissolved COPCs over time at the site; and 3) to estimate potential receptor exposure-point concentrations. Available geochemical data indicated that groundwater COPCs are biodegrading in saturated soils and groundwater. Based on sampling results and modeling, site specific biodegradation rates were estimated for several COPCs. Based on these biodegradation rates the half-life in saturated soil and groundwater for several COPCs was estimated. Benzene's half-life was estimated at 5 years. The half-life of toluene, ethylbenzene, and naphthalene were estimated at 3.5 years, 15 years, and 24 years, respectively. Even in the absence of SVE or bioventing, model simulations suggest that benzene concentrations in the plume core will decrease below the level to prevent further increases in plume size by the year 2005. Benzene concentrations should be reduced by 95 percent by the year 2017. And, benzene should be reduced below the Tier 1 RBSL of 5 mg/L at every sampling location by the year 2028.

The quantitative chemical fate assessment demonstrated that, although the dissolved plume could increase in size and concentration over the next few years, natural chemical attenuation processes will eventually be sufficient to achieve contaminant mass reduction and minimize contaminant mobility. However the fate and transport analysis suggests that it may be desirable to implement some level of source reduction at the site to limit the duration of monitoring requirements (and prevent additional adverse impacts to groundwater quality in the source area from soil and LNAPL sources).

## **Exposure Pathways Analysis**

Exposure pathway completion was reexamined to identify those receptors and pathways that realistically could be completed. Exposure pathway analysis found that only onsite intrusive and nonintrusive workers could be involved in completed exposure pathways. Based on the available data and modeling results, there are no completed pathways to current or future offsite receptors. The activities of onsite nonintrusive workers are generally confined to the paved areas of the site, and even incidental contact with contaminated soil or groundwater is unlikely. Volatilization from subsurface sources could theoretically pose an inhalation risk to onsite outdoor workers if the concrete apron is removed as part of future land use plans. However, no inhalation risk was predicted for outdoor workers when actual soil gas sampling data was used to calculate risk. No air COPC was predicted to migrate into indoor breathing zones at concentrations above the Tier 1 RBSLs. Therefore, no air exposure pathways will be complete. As discussed above, natural attenuation should be sufficient to limit plume migration by the year 2005, and reduce groundwater COPC concentrations by about 95 percent by the year 2017. No significant plume migration is expected based on conservative modeling results and no completed pathway to offsite receptors exists.

## **Development of Site-Specific Target Levels (SSTLs)**

As part of the Tier 2 analysis, site-specific target levels are developed for those chemicals detected at concentrations above the Tier 1 RBSLs, and which are involved in a completed or potentially completed exposure pathway. Given the outcome of the Tier 2 quantitative chemical fate and transport assessment, and the revised exposure pathway analysis, onsite intrusive worker exposure to site-related contamination during excavation activities was the only completed exposure pathway. Therefore, this was the only scenario for which health-based Tier 2 SSTLs were developed. In addition, SSTLs for capillary fringe soils were "back calculated" from the groundwater SSTLs to reassess the potential for onsite soils to generate COPC leachate at concentrations equal to or greater than the groundwater SSTLs.

## **Comparison of Exposure-Point Concentrations to SSTLs**

After calculation of the SSTLs, these values were compared to the site-specific contaminant levels, to determine which COPCs would require either remediation to the SSTL levels. The maximum detected concentration of soil and groundwater COPCs were conservatively assumed to represent the current and future exposure-point concentrations at Site ST-27. However, it is important to note that the future exposure-point concentrations, for onsite workers engaged in highly intrusive activities, are expected to be significantly lower than the maximum concentrations observed during the 1995/96 sampling events, due to the removal of COPCs via bioventing and natural attenuation processes.

All the low-molecular-weight soil COPCs significantly exceeded their soil leaching SSTLs (i.e., benzene, toluene, ethylbenzene, xylenes, and chlorobenzene). The leaching calculations suggest that these compounds will continue to leach from soils and have an adverse impact on underlying groundwater for approximately 8 to 10 years, if no additional remedial actions are taken. In contrast, the heavier hydrocarbon soil COPCs (i.e., 1,3,5-TMB and naphthalene) only slightly exceed their soil leaching SSTLs and will have minimal impact on underlying groundwater.

Benzene, toluene, naphthalene, and 1,2,4-TMB concentrations exceed the

health-based groundwater reasonable maximum exposure (RME) SSTLs. The maximum benzene concentration of 6,900 ppb was the only groundwater COPC to exceed its health-based SSTL (240 ppb) by more than an order of magnitude. All other groundwater COPCs are approaching their health-based SSTLs. The analytical model used to predict the long-term fate of COPCs in impacted media indicates that benzene will be reduced below its health-based SSTL by the year 2017 at every sampling location by natural chemical attenuation processes only.

## **Recommended Remedial Alternative**

Based on the initial remedial screening process, and the results of the Tier 2 analysis, several remedial approaches and technologies were retained for the development of remedial alternatives. These technologies were selected to provide a range of passive to more active response actions, all of which will minimize contaminant migration, minimize increases in contaminant concentrations, and prevent receptor exposures. The primary goal of all the candidate alternatives is to remediate Site ST-27 to a point at which no contaminant concentrations exceed Tier 2 SSTLs. The SSTLs would be met in slightly different time frames and at different costs under each alternative.

An alternative using SVE as an interim action, bioventing in the source Area, natural attenuation of groundwater, long-term monitoring, and land and groundwater use controls was recommended for remediation of Site ST-27. This selection was based on its expected effectiveness in stabilizing the dissolved plume and attaining Tier 2 SSTLs by the year 2007, its relative simplicity with respect to technical and administrative implementation, and its relatively low present worth cost of \$202,000.

## **Regulatory Approval**

In June of 1997 SCDHEC responded with a written request for additional information and/or clarification of several points, but agreed with the remediation strategy presented in the CAP. A final version of the CAP was accepted in August of 1997.

## **Remedial Action Implementation and Long-Term Monitoring**

The SVE system operated for approximately 170 days. Once TVH soil gas concentrations were reduced to acceptable levels, the SVE system was converted to an air injection bioventing system. Based on an average flow rate of 17.3 scfm and an average TVH influent concentration of 2,560 ppmv, an estimated 3,030 pounds of volatile hydrocarbons were removed during SVE operations.

At the conclusion of approximately 2 years of bioventing operations, compliance soil samples will be collected to determine the degree of contaminant reduction. If contaminant levels have been reduced to acceptable levels (i.e., below the Tier 2 soil leaching SSTLs), the bioventing system will be deactivated. Based on results from the pilot tests performed at Site ST-27, 2 years should be adequate to reduce COPC concentrations in contaminated soils at Site ST-27 to below Tier 2 soil leaching SSTLs. During the dry season, the fuel residuals in the capillary fringe will be "dewatered" and available for bioventing.

Ten years of long-term groundwater monitoring is proposed to verify that engineered source reduction technologies and natural chemical attenuation processes are sufficient to achieve the desired degree of remediation. The proposed remedial alternative for this site calls for groundwater sampling every year until

SSTLs are attained at every sampling location. Additionally, 2 years of verification sampling will be performed after SSTLs are attained to confirm plume stability.

A total of 10 wells (5 wells within the plume and 5 point of action wells outside of the plume) will be used to monitor the stability of the dissolved COPC plume at the site over time. The purpose of the monitoring events are to confirm that natural chemical attenuation processes are reducing COPC concentrations and limiting mobility. These wells are located within and surrounding the characterized areal extent of the dissolved COPC plume to ensure that implemented remedial actions and natural chemical attenuation processes are sufficient to attain all SSTLs and ensure plume containment.

## **Verification of Land and Groundwater Use Controls**

An important element of the recommended corrective action at Site ST-27 is land and groundwater use controls. On the basis of the exposure pathways analysis, Site ST-27 is and will continue to be acceptable for continued industrial use provided nonintrusive workers do not come into direct contact with impacted media on a regular basis, and intrusive workers do not engage in excavation activities that disrupt the concrete apron near the source area without appropriate personal protective equipment. It is recommended that access to the site continue to be restricted. This action will prohibit unauthorized site access and unplanned ground disturbance.

The target cleanup objectives also are based on the assumption that future land use will not require extraction of shallow site groundwater for potable uses. Any future lease or new land use of this land must stipulate that shallow groundwater will not be extracted within 1,000 feet of detected dissolved contamination until COPC concentrations have been reduced below applicable concentrations.

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# **The Air Force BIOCHLOR Natural Attenuation Model and Database for Chlorinated Solvent Sites**

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## **Abstract**

The Air Force Center for Environmental Excellence (AFCEE) Technology Transfer Division is now completing the development of a planning-level natural attenuation model and database for chlorinated solvent sites. The model, called BIOCHLOR, will have the same look-and-feel as the BIOSCREEN model developed for AFCEE for petroleum hydrocarbon sites but will include customized biodegradation features for simulating chlorinated solvent sites. In addition, a 25-site chlorinated solvent database is also being developed to support the BIOCHLOR model. BIOCHLOR can also be used in the site screening process in the AFCEE's Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater (Wiedemeier et al., 1996).

## **Overview of Natural Attenuation**

"Natural Attenuation" refers to naturally-occurring processes in soil and groundwater environments that act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in those media. These in-situ processes include biodegradation, dispersion, dilution, adsorption, volatilization, and chemical or biological stabilization or destruction of contaminants (OSWER, 1997). For chlorinated solvent sites, biodegradation via reductive dechlorination is an important natural attenuation process.

## **Reductive Dechlorination as Sequential Reactions**

Biodegradation can often be a dominant process in the natural attenuation of chlorinated solvents. At chlorinated solvent contaminated sites, the majority of solvent biodegradation occurs by reductive dechlorination. Reductive dechlorination is a microbially-mediated reaction whereby a chlorine atom on the chlorinated solvent is replaced by a hydrogen atom. Typically in biological processes, the organic contaminant acts as an electron donor and another substance (such as oxygen, nitrate, etc.) acts as the electron acceptor. However, during reductive dechlorination, hydrogen acts as the electron donor and halogenated compounds, such as chlorinated solvents, act as electron acceptors and thus

become reduced, as shown in the following half reaction:



Figure 1 shows the reductive transformation pathways for the common chlorinated aliphatics.

*(not furnished)*

Figure 1. Reductive Transformation Pathways for Common Chlorinated Aliphatic Hydrocarbons.

Reductive dechlorination can be described as a sequential first order decay process. This means that a parent compound undergoes first order decay to produce a daughter product and that product undergoes first order decay and so on. Generally, the more highly chlorinated the compound, the more rapidly it is reduced by reductive dechlorination (Vogel and McCarty, 1985; Vogel and McCarty, 1987). Therefore, it is possible for daughter products to increase in concentration before they decrease as shown in Figure 2. BIOCHLOR accounts for sequential first order decay of this nature, and this sets it apart from BIOSCREEN which models the biodegradation of fuel hydrocarbons via first order decay or electron acceptor-limited (instantaneous reaction) processes.

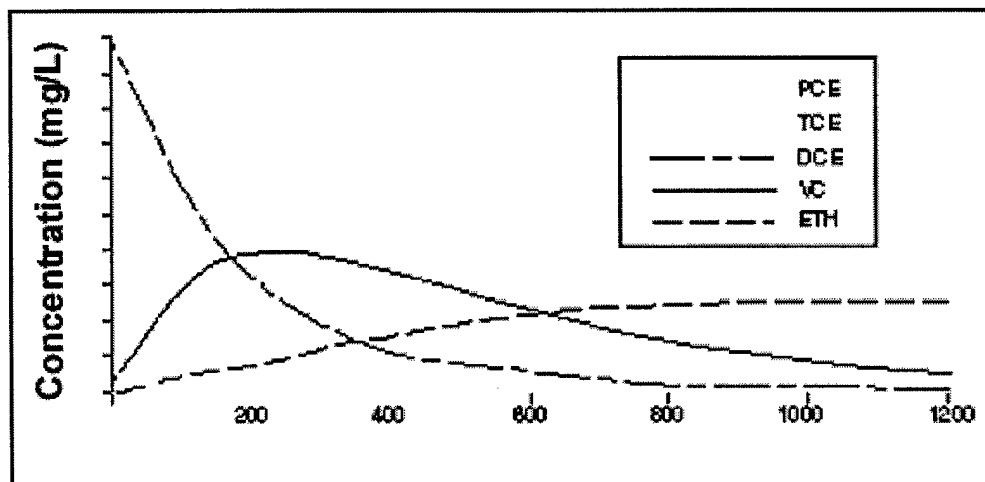


Figure 2. Concentration Patterns of Parent Compound (PCE) and Daughter Products in Sequential Reductive Dechlorination Reactions.

### Innovative Solution Scheme in BIOCHLOR

Although BIOCHLOR shares a similar interface to BIOSCREEN, the underlying equations and solution scheme are considerably different in order to accommodate the reactive transport of up to five chlorinated solvents. A novel solution scheme developed at the Battelle Northwest National Laboratory is employed whereby mathematical transformations are applied to the coupled partial differential equations describing the reactive transport of the chlorinated solvents in the subsurface. As a result of the transformation, the partial differential equations are uncoupled and then solved using the Domenico equation. An inverse transformation yields the concentration profiles. By employing this novel solution scheme, the reactive transport equations can be simply and quickly solved in a spreadsheet environment.



## BIOCHLOR User Interface

The BIOCHLOR interface is an easy-to-use, spreadsheet-based system that requires Microsoft Excel. The user enters data on a single input screen with the assistance of pop-up menus and an on-line help feature. Two types of output can be evaluated: i) centerline concentration data for all parent and daughter compounds, ii) centerline concentration data for individual compounds, and iii) a 2-D array of data. The three interface screens in the model are attached at the end of this paper.

## Chlorinated Solvent Site Database

In addition to the BIOCHLOR model, a companion database of 25 chlorinated solvent sites was compiled. Assembled information included data such as chlorinated solvent plume lengths, widths, and concentrations, source characteristics, hydrogeological parameters, and electron acceptor concentrations. The site data was then analyzed for trends with respect to plume length. For example, the median plume length of PCE, TCE, *cis*-1,2-DCE, vinyl chloride, and ethene for the 25 sites studied was 265 ft, 1000 ft, 1190 ft, 700 ft, and 600 ft, respectively. Summary statistics for key variables are presented below.

	Plume Length (ft)	Plume Width (ft)	Plume Thickness (ft)
Max.	9000	3000	79
75th percentile	3150	1450	43
median	1250	675	29
25th percentile	665	308	20

	MAXIMUM CONCENTRATION (mg/L)			
	PCE	TCE	<i>cis</i> -DCE	VC
Max.	49.	570.	300.	6.520
75th percentile	0.741	15.05	10.90	2.600
median	0.034	3.255	1.295	1.300
25th percentile	0.002	0.307	0.178	0.083

## Intended Uses for BIOCHLOR

BIOCHLOR attempts to answer the following fundamental question regarding RNA:

- How far will the dissolved contaminant plume extend if no engineered controls or further source zone reduction measures are implemented?

BIOCHLOR uses an analytical solute transport model with sequential first order decay for simulating in-situ biodegradation. The model will predict the maximum extent of plume migration, which may then be compared to the distance to potential points of exposure (e.g., drinking water wells, groundwater discharge areas, or property boundaries). Analytical groundwater transport models have seen wide application for this purpose (e.g., ASTM 1995) and experience has shown such models can produce reliable results when site conditions in the plume area are relatively uniform.

BIOCHLOR is intended to be used in two ways:

1. As a screening-level model to determine if RNA is feasible at a site.

In this case, BIOCHLOR is used early in the remedial investigation as a supporting line of evidence to determine if natural attenuation is occurring at sufficient rates at a site. Some data, such as biodegradation rate constants, may not be available, so typical values are used. Other useful attributes of BIOCHLOR include the facilitation of site characterization data organization and the ability to carry out many simulations in short periods of time.

2. As the primary RNA groundwater model at smaller sites.

The Air Force Intrinsic Remediation Protocol (Wiedemeier et al., 1996) describes how groundwater models may be used to help verify that natural attenuation is occurring and to help predict how far plumes might extend under an RNA scenario. At large, high-effort sites such as Superfund and RCRA sites, a more sophisticated model such as RT3D is probably more appropriate. At less complicated sites with simple hydrogeology, such as small dry cleaner sites, BIOCHLOR may be sufficient to model natural attenuation. Note that in most cases, BIOCHLOR will not be used as the sole line of evidence to demonstrate natural attenuation, but as a supporting line of evidence together with concentration vs. time data, the presence of geochemical indicators, etc.

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## Biographical Sketches

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# **Remediation Technologies Screening Matrix and Reference Guide: Version III**

## **Background**

The U.S. Army Environmental Center (USAEC) is leading an effort to update the Remediation Technologies Screening Matrix and Reference Guide, Third Edition under the auspices of the Federal Remediation Technologies Roundtable (FRTR). The purpose of the update is to create a comprehensive "Remediation Technologies Yellow Pages" for use by those responsible for environmental cleanup. The Guide is being produced as a multiagency cooperative effort published under the FRTR. Members of this effort include USAEC, the U.S. Army Corps of Engineers (USACE), the Naval Facilities Engineering Service Center (NFESC), the Air Force Center for Environmental Excellence (AFCEE), the Environmental Protection Agency (EPA), the Department of Energy (DOE), the Department of the Interior (DOI), and the Interstate Technologies Regulation Cooperative (ITRC). This manuscript provides a comprehensive look at environmental technology information provided in the electronic user-defined Remediation Technologies Screening Matrix and Reference Guide.

As environmental technology continues to evolve, the volume of available information increases. We envision that this "living" dynamic document will ease the burden of sorting through large masses of related and overlapping information to evaluate alternative technologies. Traditionally, Remedial Project Managers (RPMs) and other remediation professionals were forced to look through numerous references and material just to get a grasp on available technologies that fulfill their remediation needs. Often, the information gathered was neither state of the art nor completely up to date. The Guide provides a time-saving compilation of commonly recognized remediation technologies and provides RPMs with a "one-stop-shopping" arena to make preliminary technology selection decisions. The intent of the Guide is not to limit RPMs and others to base decisions solely on the Guide's information, but rather to use the information to perform an improved, direct, guided search.

The previous editions of the Guide were published as paper documents. These documents were highly visible and useful, but with the advent of the World Wide Web (WWW), methods of information exchange are rapidly changing. The WWW provides a cheap, efficient way to disseminate and share information. The update committee decided that the third edition of the Guide would be an electronic, on-line document.

Various web browsers exist to assist RPMs in their search for specific cleanup information on the WWW; however, currently, no system exists that both provides a basic understanding and knowledge of cleanup technology alternatives for a given site condition. The main advantage of the Guide is that it organizes and indexes the technologies real-time to the best and most readily available information from numerous interagency and private WWW homepage references. Also significant is the high level of cooperation and review among all the aforementioned federal agencies. Basing the Guide on the WWW has numerous other advantages over the paper-copy version.

1. Document size is no longer a limiting factor. The second edition had

become impractical because it was 700 pages in print. Additional data about technologies and other extraneous information into the third edition would warrant a multi-volume document. As a paper copy, this edition would not only be expensive to produce, but also intimidating and unwieldy.

2. Through the WWW, we now have the ability to hyperlink from the Guide to other government and private group web pages. Not only does this serve as a Point of Contact (POC) list, but it also allows RPMs to discover remedial sites utilizing the technology. The hyperlinks to WWW references allow RPMs to read about different experiences with a technology beyond the general descriptions of applicability, cost, and limitations found in technology profiles.
3. Future WWW updates of the Guide will be less expensive and time-consuming. The technology descriptions are now more general, and their information is not controversial. Updating will also be easier because the Guide can be reviewed on line, have information modernized, and hyperlinks checked. The WWW allows for easy modification and addition of technologies.
4. Through the WWW, the Guide will contain the most current information available. It is a simple task to add new links or information to a web page. Compared with reprinting an entire document, hyperlinking is time-saving and keeps documents up to date and useful.
5. Updating information on web pages hyperlinked outside of the Guide will be the responsibility of the outside web site owners. Therefore, there is no need for a centralized location for the posting of new agency technology information.

The FRTR Screening Matrix and Reference Guide is arranged to make information gathering easy for RPMs. The Screening Matrix is organized in six chapters.

1. Introduction
2. Contaminant Perspectives
3. Treatment Perspectives
4. Treatment Technology Profiles
5. References
6. Appendices

## **(Chapter 1) Introduction**

The Introduction of the Guide provides users with discussions on document structure; objectives; developmental background; pertinent information about authors, contributors, and supporters; usage guidance; and, most important, the limitations of using the Guide. The member agencies are recognized for their contributions, effort, and support to the project. Individuals who donated time to review and comment on the draft are also acknowledged.

## **(Chapter 2) Contaminant Perspectives**

The Contaminant Perspectives chapter enables RPMs to determine potential treatment technologies based on applicability to both the contaminated media and the contaminant group. It is broken down into five major contaminant groups.

1. Volatile Organic Compounds (VOCs)

2. Semivolatile Organic Compounds (SVOCs)
3. Fuels
4. Inorganics (including radioactive elements)
5. Explosives

The different technologies used to deal with VOCs and SVOCs have been further categorized in the third edition as Halogenated and Nonhalogenated VOCs and SVOCs. Each applicable technology for the remediation of the contaminant group is listed on a matrix. The matrix graphically describes the development status, use rating, applicability, and the technology function. The contaminant perspective matrix is a shortened version of the treatment technology matrix. The contaminant groups' properties and behaviors are described to help RPMs generally determine the amount of site characterization necessary, based on the historic land use.

### **(Chapter 3) Treatment Perspectives**

The Treatment Perspectives chapter identifies the 14 major treatment group categories. The category descriptions compare the technologies within the areas to each other in dealing with a variety of contaminants. These treatment areas include:

1. in situ biological treatment for soil, sediment, and sludge;
2. in situ physical/chemical treatment for soil, sediment, and sludge;
3. in situ thermal treatment for soil, sediment, and sludge;
4. ex situ biological treatment for soil, sediment, and sludge;
5. ex situ physical/chemical treatment for soil, sediment, and sludge;
6. ex situ thermal treatment for soil, sediment, and sludge;
7. other treatments for soil, sediment, and sludge;
8. in situ biological treatment for groundwater, surface water, and leachate;
9. in situ physical/chemical treatment for groundwater, surface water, and leachate;
10. ex situ biological treatment for groundwater, surface water, and leachate;
11. ex situ physical/chemical treatment for groundwater, surface water, and leachate;
12. other treatments for groundwater, surface water, leachate;
13. air emissions/off-gas treatment; and
14. containment.

The Treatment Perspectives chapter provides a list of environmental remediation site information based on completed projects. Site information can be further analyzed by RPMs to gain a greater knowledge of real-life application of a particular technology. The site information is based on the EPA's "Completed North American Innovative Remediation Technology Demonstration Projects."

A distinct feature of the Guide is the enlarged version of the Treatment Technology Screening Matrix. This Matrix gives general ratings of better, average, or worse for each of the technologies in the Guide compared to the contaminant which is to be treated. It is the intent of this Matrix to give RPMs a rapid visual idea of the technologies' strengths, weaknesses, developmental status, availability, residuals produced, necessity of a treatment train, reliability, and cost information.

### **(Chapter 4) Treatment Technology Profiles**

The Treatment Technology Profiles chapter is the most utilized and recognized portion of the Guide. It is typically a four-page write-up describing the basics of the technology. This chapter is the bulk of the document and was in the greatest

need of being updated. It enables RPMs to gather basic knowledge of technologies, which aids in the preparation of a detailed analysis of numerous remedial action alternatives.

Each of the 64 profiles contains the following information.

1. **Description**—The technology description is a one-paragraph overview of the technology and the principles it is based on. The Guide describes the principle of the method, but does not get into the mechanics of the technology.
2. **Schematic**—The schematic provides a graphic depiction of a typical technology layout. Where there are photographs of a technology, they have been scanned and added electronically to the technology profile.
3. **Synonyms**—During the update, it was discovered that various agencies developed similar technologies, but named them differently. Providing technology profiles for each technology nuance would be confusing and of limited value. The primary objective is to educate users on the variety of names they may encounter during a detailed technology search.
4. **Applicability**—This section details the contaminant class, media, or operating conditions in which the technology tends to operate best. This enables RPMs to understand how technologies are suitable to their contaminated site.
5. **Limitations**—Sometimes, it is more important for RPMs to know what the technology cannot do, rather than what it can. The limitation section warns of possible difficulties of technologies, conditions under which the technology's success may be minimal, or special precautions necessary when implementing the technology. Remediation is very site-specific, and technologies should be matched to fulfill the needs of the site.
6. **Data Needs**—This section differs from limitations because it describes variables that must be considered before utilizing a technology. It describes site characterization and information gathering necessary before technology implementation.
7. **Performance Data**—This section describes results when the technology was implemented and information was gathered regarding its performance. This allows RPMs to gauge how successfully their site could be using the technology compared to other sites that have used it.
8. **Cost**—This section quantifies a range of costs involving technology used in a typical remediation situation. It also describes possible hidden costs, pretreatment costs, and cost-saving lessons learned. The FRTR has provided guidance on collecting cost and performance data by publishing the "Guide to Documenting Cost and Performance for Remediation Projects." Individual agencies have been independently creating reports on their findings in a variety of sites. Whenever possible, the performance data and cost subsections were linked to other technology-specific web sites containing pertinent cost and performance information.
9. **References**—The information in the profile came from a variety of sources. These sources are listed in the Reference section and, whenever possible, hyperlinked on-line on the WWW. This allows for quick, efficient access to technology data.

10. **Site Information**—The information in this section overlaps information in chapter 3. It presents the site information from the completed "North American Innovative Remediation Technologies Demonstration Projects" and discusses specific technology rather than treatment perspective.
11. **Points of Contact**—The POC section contains two parts. The first part of the POC subsection provides a general list of individuals and agencies that contributed to updating the Guide. This list is hyperlinked to the agencies' homepages. The second part of the POC section is one of the most useful sections of the Guide; it links the technology profile to both private and government technology-specific web pages. This allows users to discover what private sector and government POCs are reporting about their technologies.
12. **Vendor Information**—This section leads users to a list of vendors compiled using the EPA's Vendor Information System for Innovative Treatment Technologies (VISITT) database. Vendors are grouped according to technology perspectives categories. The vendor therefore has the opportunity to provide solutions to general contaminant problems. The government does not validate or promote any of these companies, nor it is a complete list, but it has been created as a tool for RPMs to seek further information.
13. **Health and Safety Information**—The Health and Safety Information section is being provided by the an USACE expert. This information includes factors that RPMs should consider when evaluating a specific technology. RPMs can gain a better understanding of special circumstances or precautions necessary for the implementation of the technology.

## **(Chapter 5) References**

The Reference chapter lists the journals, guides, papers, and reports from which information was compiled to complete the document. The committee's goal was to compile information in a neutral, user-friendly platform, rather than create new material. The complete list of references is provided and, whenever possible, linked to locations on the WWW. Users of the Guide can either download the report off the WWW or view it on-line. Ordering information for documents not available in electronic copy is available through the National Technical Information Service (NTIS).

## **(Chapter 6) Appendices**

The Appendices provide additional information above and beyond that contained in the Guide itself. Hyperlinks to other federal databases and information sources are provided. Users can follow up on information gathered from the technology profiles or contaminant information. The appendices also contains environmental vendor information through the EPA VISITT database, DOE Site Remediation Technologies Contaminant Matrix, and a general list of factors affecting treatment cost and performance. The appendices have also been modified to include more information and hotlinks to environmental restoration data during the update effort.

## **Conclusion**

The intent of this project was to transform the FRTR Remediation Technologies



Screening Matrix and Reference Guide from a paper document to an electronic one. The Guide is well indexed and cross-referenced through hyperlinking to similar information contained elsewhere on the WWW. Users may still obtain paper copies of this document by printing individual sections directory from the WWW. In addition, a separate electronic CD-ROM version will be produced for anyone who that may not have access to the WWW at this time. The disadvantage of the CD-ROM version is that it would be a single snapshot of the Guide on the WWW at the time of the CD-ROM's creation. Any new information that a federal agency publishes on its WWW homepage tomorrow would not be included on the CD-ROM version created today.

The investment of time and effort required to complete the updating and cross-referencing of the document is expected to result in a time and effort savings that is multiplied over and over again for each user of the document, using the Guide's "one-stop-shopping" format. In addition, successful completion of this project is expected to foster and demonstrate closer cooperation among DOD and all Federal agencies and provide an improved technology transfer product to both environmental technology users and the research and technology development community.

The transition from a paper document to a WWW electronic version has been gradual. Although primarily produced as a paper copy, version two of the Guide was made available on the FRTR WWW homepage at <http://www.frtr.gov>. Version three was released on 15 November 97 and replaced version two on the FRTR webpage. If you have any questions or comments about the Guide, please contact Dennis Teefy via email at [t2hotline@aec.apgea.army.mil](mailto:t2hotline@aec.apgea.army.mil).

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# Pulse Biosparging of Hydrogen for the In-situ Biodegradation of Chlorinated Solvents

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## Abstract

This paper summarizes recent published laboratory research and technology development efforts related to using direct hydrogen delivery as a remediation approach for managing chlorinated solvent plumes. Because of hydrogen's low cost, its ability to be delivered safely and inexpensively in a variety of ways, and its ability to promote rapid dechlorination, direct hydrogen addition represents a potentially superior approach for managing and remediating chlorinated solvent groundwater plumes. Currently, the Air Force Center for Environmental Excellence (AFCEE/ERT) is conducting a 7-site evaluation program based on a groundwater recirculation system approach to directly deliver dissolved hydrogen to groundwater. The original test design called for the recovery of contaminated groundwater, amending it with hydrogen, and then reinjecting the contaminated groundwater and dissolved hydrogen back into the subsurface.

Due to regulatory constraints associated with this closed-loop recycling process, AFCEE/ERT is now considering field testing **short-pulse biosparging**, wherein a short duration (15 to 120 second) pulse of hydrogen gas is directly sparged into an affected groundwater zone. Hydrogen injected in this manner is trapped as residual bubbles after the pulse is stopped, the residual gas bubbles are allowed to dissolve (initial estimates allow a week for dissolution), and the process is repeated. A weekly pulse-application schedule precludes the need for expensive and disruptive gas distribution equipment installed on the surface, as a manual hydrogen delivery system could be employed. The field test will address and evaluate several engineering factors related to pulsed hydrogen biosparging: i) safety, ii) air channeling of the sparged gas, iii) mass transfer efficiency, and iv) difficulty in predicting site-specific applicability.

## Background

Although generally regarded as recalcitrant, chlorinated hydrocarbons are known to undergo natural (unassisted) dechlorination in the field (Gossett and Zinder, 1996; Wiedemeier et al., in press). Typically, the rate of natural dechlorination is

severely limited by the lack of adequate electron donor quantities (e.g., hydrogen). At sites where natural dechlorination has been observed, organic substrates such as aromatic hydrocarbons (BTEX), landfill leachate, or other non-chlorinated organics have been noted to be a source of dissolved hydrogen, produced through slow fermentation of these organics. The hydrogen is then rapidly utilized as an electron donor by naturally-occurring bacteria to achieve reductive dechlorination of chlorinated compounds in the subsurface.

However, whereas natural attenuation is expected to be able to control nearly 80%-90% of sites impacted by fuel hydrocarbons due to the high biodegradation rates associated with aerobic and anaerobic processes for these constituents, "natural attenuation alone may only apply to 20% of all chlorinated solvent sites" (Wilson, 1996, as reported by Haas, 1996). This information suggests that effective plume management technologies for chlorinated solvent sites (either barriers or active source zone remediation techniques) will be required.

## **Laboratory Studies of Dechlorination**

Based on the results of recent research, the role of hydrogen as electron donor is now widely recognized as the key factor governing the biologically-mediated dechlorination of these common environmental contaminants (DiStefano et al., 1992; Maymo-Gatell et al., 1995; Gossett and Zinder, 1996; Smatlak et al., 1996; Fennell et al., 1997; Ballapragada et al., 1997; Hughes et al., 1997; Newell et al., 1997; Carr and Hughes, 1998). However, most attempts to capitalize on this process have focused on providing fermentation substrates such as lactate or benzoate to produce low concentrations of dissolved hydrogen, which is then used by dechlorinating bacteria as an electron donor for biological reductive dechlorination. (Note that hydrogen is a by-product of the fermentation process.)

More recently, the results of long-term (>1 yr) laboratory column studies completed at Rice University indicate the potential for stimulating and sustaining dechlorination activity through direct hydrogen addition (Carr and Hughes, 1998). With this approach, conceived by J. Hughes, the addition of fermentation substrates is eliminated and hydrogen is delivered directly without any intermediate biological reactions (see delivery systems discussion below). In the laboratory experiments, six continuous-flow recycle columns, configured as shown in Figure 1, were operated for a period of 474 days. The columns were assembled using bacterial enrichment cultures derived from two independent sources: 1) an anaerobic granular sludge obtained from a sludge blanket reactor used to treat industrial wastewater containing no known chlorinated solvents, and 2) aquifer solids (soil cores) obtained from a chlorinated ethene contaminated site. Three columns were inoculated with the granular sludge-derived enrichment culture, and three columns were inoculated with a 1:1 mixture of the granular sludge and aquifer solids-derived enrichment cultures. One column from each inoculum subset was fed either a fermentable substrate (methanol or lactate), or hydrogen as an electron donor. Liquid medium was circulated continuously through the columns at a flow rate of 2 mL/min, and the columns were spiked with PCE every four days to produce an initial concentration of approximately 5 mg/L PCE following each injection.

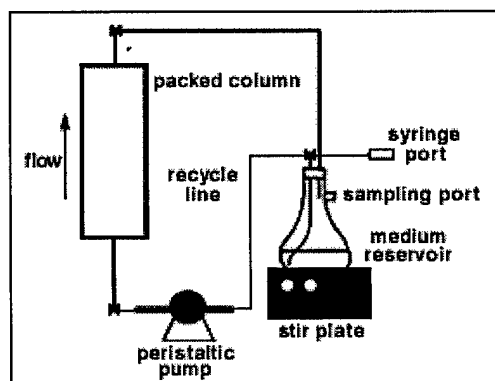


Figure 1. Typical Configuration of Apparatus for Dechlorination Column Experiments.

Typical results for PCE reduction in the hydrogen-fed columns are shown on Figure 2 and Figure 3 at day 106 and day 129 of column operation, respectively. As indicated on Figures 2 and 3, the observed rate of PCE reduction was quite rapid, with computed PCE half-lives on the order of hours (Table 1). Note from Table 1 that the rate of PCE dechlorination was observed to increase with time such that, by day 474 of column operation, the estimated PCE half-life within the columns was less than 2 hours. The extent of dechlorination was also observed to increase with time (Table 2), as determined by the molar distribution of final end products measured at 4 days following each PCE injection spike. The relatively large fraction of vinyl chloride remaining in the system after 427 days is largely an artifact of the experimental design, as the large Henry's Law coefficient for vinyl chloride resulted in much of the produced vinyl chloride being sequestered in the gas exchange vessel (see Figure 1).

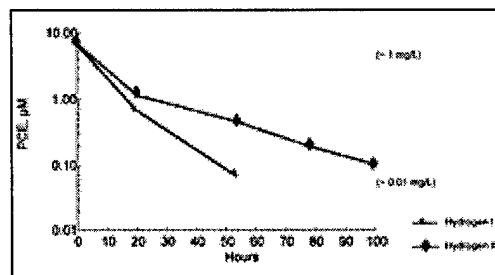


Figure 2. PCE Reduction in Hydrogen-Fed Columns, Day 106.

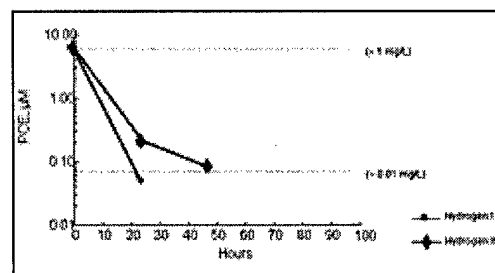


Figure 3. PCE Reduction in Hydrogen-Fed Columns, Day 129.

**Table 1. Observed PCE Half-Lives in Hydrogen-Fed Laboratory Columns**

Column	Observed PCE Half-Life		
	Day 98	Day 129	Day 474
Hydrogen I	5.6 hr	3.5 hr	<2 hr
Hydrogen II	16.1 hr	7.8 hr	<2 hr

**Table 2. Percent Molar Distribution of Dechlorination End Products in Hydrogen-Fed Columns Following 4-Day Incubation Period**

Constituent	Molar Recovery (%)		
	Day 98	Day 129	Day 427
<b>Hydrogen I</b>			
PCE	0.0	0.0	0.0
TCE	0.0	0.2	0.0
cis-DCE	95.9	8.7	0.0
VC	4.1	86.7	80.2
Ethene	0.0	4.4	19.8
<b>Hydrogen II</b>			
PCE	5.9	1.2	0.0
TCE	0.0	0.2	0.0
cis-DCE	0.0	3.2	0.0
VC	94.1	83.1	75.9
Ethene	0.0	12.5	24.1

Results observed for the fermentable substrate-fed (methanol and lactate) columns were similar to those observed for the hydrogen-fed columns (i.e., same dechlorination rate and extent), indicating that, "dechlorination was not impacted by competition for electron donor at high hydrogen partial pressures (ca., 0.8 atm) by other hydrogen-utilizing microorganisms, particularly methanogens" (Carr and Hughes, 1998). These observations led the authors to conclude that, "issues such as cost and method of delivery may dictate the electron donor (i.e., fermentable substrates vs. hydrogen) selected for stimulation of anaerobic in-situ bioremediation systems" (Carr and Hughes, 1998).

## Hydrogen Delivery Methods

Direct hydrogen addition is a highly flexible process that may be implemented in a variety of process configurations for either dissolved plume management or reduction of NAPL source zones, depending upon the goals of the intended remediation effort (see U.S. Patent No. 5,602,296, Hughes et al., 1997; Newell et al., 1997). Potential delivery methods include:

- Dissolved hydrogen injection via groundwater recirculation system
- Short pulse bioparging
- In-situ controlled release reaction (hydrogen releasing agent)
- Injection of hydrogen gas aphrons (surfactant/hydrogen gas microbubbles)
- In-situ electrolysis of water (as described by Hughes et al., 1997)

A project to field test direct hydrogen addition is currently underway through the

Technology Transfer Division, Air Force Center for Environmental Excellence (AFCEE/ERT), Brooks AFB, Texas. The initial test program, designed by Patrick Haas of AFCEE/ERT, consists of both short-term (1 week) treatability tests and long-term (1 year) pilot tests at select Air Force installations. The treatability tests are designed as site screening tests that evaluate hydrogen utilization by indigenous microorganisms via a field test method known as "push-pull." This type of test has been described by Istok et al. (1997) for use in determining microbial activities related to degradation of petroleum hydrocarbons. The year-long pilot tests involve recovery of contaminated groundwater, amendment with dissolved hydrogen, and subsequent reinjection of the groundwater flow stream using a two-well groundwater recirculation system.

During the initial phase of this project, regulatory approval could not be obtained in some areas for the reinjection of recovered groundwater due to the presence of contaminants, even when reinjection was part of a closed-loop groundwater treatment system as described above. Therefore alternative delivery systems were evaluated, with pulsed biosparging being selected as the next best approach.

### **Hydrogen Delivery by Pulse Biosparging**

Sparging is a remedial technique whereby a gas (typically air) is injected into the saturated zone, forming gas channels between the injection point and the unsaturated zone (Johnson et al., 1993). In a conventional air sparging system, which operates with air flowrates in the 2 to 16 scfm range, volatile organic compounds are removed from the treatment area primarily by the mechanisms of volatilization and stripping. By contrast, *biosparging* is designed to stimulate in-situ biodegradation processes while minimizing volatilization. As reported in the literature, this is typically accomplished by applying relatively low gas flowrates to the sparge points (e.g., <1 scfm). A key factor governing the potential effectiveness of hydrogen biosparging is the efficient delivery of hydrogen. Recently, in air sparging practice, it has been discovered that pulsing the gas flow results in greatly improved contaminant mass removal rates versus continuous sparging. For example, Clayton et al. (1995) observed mass removal rates to increase when a pulsed air sparging regime using a pulse frequency between 12 and 24 hours replaced continuous air sparging. Increased groundwater mixing was cited as the reason for the observed increase in mass removal. Physical groundwater displacement and groundwater movement resulting from capillary pressure gradients were identified as the two most likely and effective mechanisms for the increased mixing.

Based on a concept developed by Dr. Paul Johnson (personal communication, 1998), the conceptualized hydrogen biosparging system uses a slightly different approach from the low-flowrate air biosparging systems discussed in the literature, in an attempt to increase the mass transfer of hydrogen to groundwater. To take advantage of the increased mixing associated with high flowrate, pulsed operations, a moderate to high (10-15 scfm) pulse of hydrogen gas is injected into the sparge points, but only for a very short duration (15 to 120 seconds). In theory, the moderate to high flow rate will help to create a dense network of gas channels that form trapped residual hydrogen bubbles after the injection pulse stops. It is hypothesized that the short duration (based on delivering approximately 10% gas saturation in a 10 ft interval around the delivery well) will eliminate or minimize hydrogen breakthrough to the surface, a hypothesis that will be tested carefully in the field. Based on preliminary results from a high-pressure pure oxygen biosparging field experiment performed by Dr. Johnson (personal communication, 1998), an initial estimate for the life-time of the biodegradable gas bubbles formed in the saturated zone is on the order of a week. This indicates that a weekly application of hydrogen may be sufficient to maximize gas transfer. Although

mass transfer is a critical concern for any sparging application, hydrogen's relatively high diffusivity ( $4.2 \times 10^{-9} \text{ m}^2/\text{sec}$ ), should provide for some limited increase in mass transfer rates relative to air sparging.

## Hydrogen Biosparging Demonstration

There are three key performance/safety issues associated with implementation of a hydrogen biosparging system. Most importantly, the ability to deliver hydrogen to the contaminated groundwater in a safe and reliable manner must be demonstrated. To address this issue, a detailed vadose zone monitoring program for hydrogen gas is to be included in the hydrogen biosparging study. Such a vadose zone monitoring program will provide data concerning hydrogen breakthrough to the surface during sparging operations. Monitoring for hydrogen in the vadose zone will be performed using hand-driven sampling points and a field hydrogen meter. The relationship between pulse flowrate/duration and breakthrough of hydrogen to the surface can then be evaluated as part of the proposed technology demonstration.

A second key performance issue is the effectiveness of hydrogen mass transfer and the efficiency of hydrogen consumption. At some sparging sites, particularly ones with coarse-grained media (Clayton 1998), air channels will form from the sparging point to the water table, greatly reducing the mass transfer of the sparged gas to the liquid phase. To address this issue, conservative tracers (such as sulfur hexafluoride and helium) will be injected in conjunction with hydrogen. Hydrogen and tracer gas concentrations will be monitored in the saturated and unsaturated zones to assess the degree of gas transfer to the liquid phase and the subsequent consumption of hydrogen. In addition, the amount of chlorinated solvents degraded can be compared with the amount of hydrogen consumed to estimate the efficiency of hydrogen utilization for dechlorination.

A final performance issue is the overall effectiveness of hydrogen biosparging for chlorinated solvent degradation. To address this issue, wells downstream of hydrogen sparge points may be monitored over time to determine the rate and extent of chlorinated solvent removal. To ensure that solvent removal is occurring biologically, two types of field controls may be employed: 1) the installation and sampling of monitoring wells outside the hydrogen sparging zone to compare the rate of natural attenuation to that of hydrogen biosparging (This control would allow the added benefits of hydrogen addition to be assessed.) and 2) sparging nitrogen at the same rate and frequency as hydrogen in an adjacent well in order to quantify any chlorinated solvent losses that may be attributable to volatilization. Figure 4 shows the configuration of sparge points and monitoring wells that is now being considered for a hydrogen biosparging pilot study.

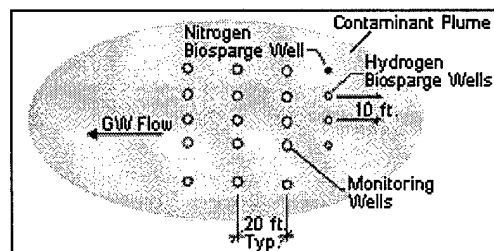


Figure 4. Schematic Diagram of Hydrogen Biosparge Demonstration System.

An overall concern with any sparging program is that there is considerable difficulty in predicting the site-specific performance of the process. The AFCEE/ERT test program will try to address this problem by performing the test

in at least two field locations. If successful, additional sites will be evaluated.

## Summary

Direct hydrogen addition, wherein hydrogen is delivered without the use of fermentation substrates or carbon sources, is a new remediation technology for chlorinated solvent plumes that is currently under development. Recent laboratory tests conducted by Carr and Hughes (1998) indicate that biological dechlorination is, "not impacted by competition for electron donor at high hydrogen partial pressures" and that, "issues such as cost and method of delivery may dictate the electron donor (i.e., fermentable substrates vs. hydrogen) selected for stimulation of anaerobic in-situ bioremediation systems."

The Air Force Center for Environmental Excellence (AFCEE/ERT) has developed a technology demonstration program involving hydrogen delivery via a groundwater recirculation system (Newell et al., 1997). Because of regulatory constraints associated with reinjection of contaminated groundwater, a new approach that is now being considered for direct hydrogen delivery is short-pulse biosparging, as conceived by P. Johnson. Under this approach, short duration pulses of hydrogen gas are sparged to the subsurface at regular intervals (approximately weekly), forming residual gas bubbles that slowly dissolve before the next pulse is added. The AFCEE/ERT field test is designed to determine if: i) pulse biosparging of hydrogen can be conducted in a safe and reliable manner, ii) pulse biosparging will allow high enough rates of mass transfer from the gas phase to the liquid phase so that hydrogen can be efficiently delivered to the contaminated groundwater, and iii) delivery of hydrogen will stimulate reductive dechlorination of the chlorinated solvents.

## Acknowledgments

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# **Lead-Based Paint Hazard Control**

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## **Abstract**

Lead-contaminated paint, dust, and soil are common in and around Army residential properties, child-occupied facilities, and nonresidential buildings constructed prior to 1978. Existing technologies for routine maintenance, interim control, and abatement of lead hazards are often inefficient and costly. In addition, they often result in exposure of children and workers to lead hazards and contaminate the environment through improper controls during abatement and disposal. The Army needs a standard methodology to make decisions for the environmentally safe and cost-effective control and abatement of lead hazards in steel structures, nonresidential buildings, and family housing and child-occupied facilities. Innovative management systems and technologies, such as the Lead-Based Paint Hazard Management System (Painter-L), Hands on Skills Training (HOST) Module, chemical stabilization, real time dust monitor, self-healing overcoatings, paint removal using thermal spray and microwaves have potential to mitigate lead-based paint hazards.

## **Introduction**

Lead-contaminated paint, and dust are common in and around Army residential properties, child-occupied facilities, and nonresidential buildings constructed prior to 1978. In addition, numerous steel structures such as water tanks, bridges, aircraft hangars, antennas, ladders, poles, railings, catwalks, fire hydrants, fuel storage tanks and metal buildings were constructed using lead-based paint primers and lead-based paint coatings.

The removal of lead-based paint from steel structures and buildings is accomplished through a variety of methods, the two most common being chemical stripping and abrasive blasting. The waste that is generated from these operations is often hazardous due to the toxicity and leaching characteristics of lead. In addition, chemical strippers also introduce chemicals, such as trichloroethylene, phenol, xylene, methylene chloride, and methyl ethyl ketone, which are considered hazardous wastes under the Resource Conservation and Recovery Act (RCRA)<sup>1</sup>.

The total cost of abating lead sources Army-wide is prohibitive with existing technologies, especially considering the large stock of older Army facilities. Cost-effective technologies are needed by Army property owners to control and abate sources of lead exposure and contamination as well as to safely remove, characterize, handle, store, transport, and dispose of lead-contaminated debris. Federal environmental and housing regulations and Army Safety and Health regulations require compliance in this area. In addition to environmental concerns, worker exposure related to lead-based paint remediation and other construction activities, that disturb lead painted surfaces, is also a concern.

## **Proposed New EPA Rules**

In a proposed rule released in June 1998, EPA defined hazardous conditions for

lead in paint, and dust, and soil<sup>2</sup>. The proposed rule will set federal standards under Section 403 of the Toxic Substances Control Act (TSCA) for hazards from lead-based paint in most housing built before 1978 and in child-occupied facilities, such as day care centers. The rule identifies when lead-based paint, lead-contaminated dust, and lead-contaminated soil become hazards. It also establishes residential lead dust clean up levels and revises dust and soil sampling requirements. Lead-based paint is defined by statute as paint with a lead concentration of 1 milligram per square centimeter, or 0.5 percent by weight.

Under the new rule, EPA proposes that lead-based paint is in "poor condition" and therefore is a hazard when there are: more than two square feet of deteriorated paint on interior components with large surface areas such as inside walls, ceilings, floors, and doors; more than 10 square feet of deteriorated paint on exterior components with large surface areas such as, outside walls; or deteriorated paint on more than 10 percent of the total surface area of interior or exterior components with small surface area, such as window sills, baseboards, soffits, and trim. Under the proposed rule, post abatement cleanup must be repeated until the dust clearance standards have been met.

EPA is proposing that dust be considered a hazard based on average measurements of loading of paint in dust. Loading is the weight of lead present per unit of surface area. The proposed dust-lead standards are 50 micrograms per square foot or higher for uncarpeted floors and 250 micrograms per square foot or higher for interior window sills. Although EPA has not proposed a hazard standard for window troughs, it is proposing a dust-lead clearance standard of 800 micrograms per square foot for window troughs.

EPA is not proposing separate standards for chewable surfaces or friction and impact surfaces at this time. Under the guidance, lead-based paint in any condition on friction and impact surfaces or chewable surfaces is a hazard.

## **Steel Structures**

In the past, steel structures at Army installations such as bridges and aircraft hangars were often coated with red lead primer to protect the structures against corrosion. These structures require periodic repainting because existing paint deteriorates and peels. Recoating requires appropriate surface preparation. The cost of paint removal needed for surface preparation by abrasive blasting has increased by a factor of 5 because of environmental compliance requirements, such as containment structure, environmental monitoring, waste disposal and OSHA requirements for worker health protection.

About half of the steel structures are good candidates for overcoating if proper performance criteria (such as adhesion) and appropriate coatings with performance specifications/commercial item descriptions (CID) are used. Otherwise, the overcoating will peel off because of thermal cycling or improper adhesion to rusty surfaces. The demonstration of the criteria and materials for overcoating has the potential for a large cost avoidance because the overcoating failures will be eliminated, resulting in extending the corrosion protection and thereby the service life of the structures.

For steel structures that are not candidates for overcoating, paint removal is required. Some of the emerging removal technologies are: environmentally acceptable chemical strippers and thermal spray vitrification. A decision tree will assist in selecting the appropriate removal process based on size of the structure, fixed or movable, condition of the coating, and rusted area.

Thermal spray removal of lead based paint from immovable steel structures is very cost effective. In the thermal spray removal process, which was developed and patented by USACERL, a glass is flame sprayed onto a painted surface<sup>3</sup>. The lead-based paint is absorbed into the molten glass as it spreads over the surface. The flame spray fuses the glass layer so that lead ions diffuse into the glass and are trapped within the glass matrix, achieving partial vitrification. The difference in the thermal expansion coefficient values between the sprayed glass layer and the steel substrate cause the glass layer to spall from the surface as it cools. The crumbled glass layer and paint fragments are collected and remelted to ensure that vitrification process is complete and lead is immobilized and prevents leaching. In this process, no containment structure is required and the airborne lead levels are usually below the OSHA action level. The waste is nonhazardous and can be recycled into high end products such as roofing granules<sup>4</sup>.

## **Nonresidential Buildings**

Proposed changes in Federal requirements for lead in public and commercial buildings will increase the costs of hazard abatement to the Army. Some of the technologies for hazard control are described.

The U. S. Navy has funded the development of a real time lead dust monitor under a small business innovative research (SBIR) contract. The use of this device can result in large estimated cost avoidance because of real time analysis of airborne lead during construction or abatement activities for lead exposure assessment. Currently, a waiting time for the laboratory analysis is required. During this waiting time, worst case exposure is presumed, since recent past history under similar conditions is not available, which results in overprotection and the associated extra costs.

Encapsulants such as "Lead Barrier Compound" (LBC), made by Fiberlock technologies Inc., have been developed by industry and have been used by a few Army installations to reduce the hazards caused by peeling paint. Some encapsulant manufacturers have claimed that their products will provide lead hazard abatement for more than 15 years. The Commonwealth of Massachusetts has developed a Liquid Encapsulant Product Performance Protocol for Interior Use as well as Toxicological Assessment Protocol. The encapsulant is required to be tested in accordance with procedures set forth in ASTM E 1795-96 Standard Specification for Nonreinforced Liquid Coating Encapsulant Products For Lead Paint in Buildings. The standardized testing cost is borne by the encapsulant manufacturer. The cost of applying encapsulants is much more than regular house paint. For example, LBC is used in 7 mils dry thickness and one gallon of encapsulant will cover about 100 square feet. In comparison, one gallon of paint will cover about 300 square feet. The criteria and procedure for choosing proper encapsulant when needed versus paint will result in large cost avoidance by eliminating misapplications.

Self-healing overcoatings contain about 5-10 percent of microcapsules, which are about 20-50 microns in diameter. These capsules are filled with polymeric compounds and other chemicals that are released when the coatings are damaged or scratched, thereby covering or healing the damaged area. Self-healing coatings reduce the release of lead dust when used as overcoatings on top of lead-based paint. When used inside a building, the lead dust is reduced considerably. When used on the outside, self-healing overcoatings arrest the further increase of lead contamination in the soil due to peeling paint, which falls on the soil adjacent to buildings.

The waste from lead-based paint removal operations such as abrasive blasting is usually hazardous. Chemical stabilizers such as Blastox (tri-calcium silicate based) and Lead X (calcium phosphate based) have been developed by industry to make the waste nonhazardous, and tested by USACERL. Demonstrations of these stabilizers in conjunction with dust reduction technologies will reduce the cost of paint removal and waste disposal and result in a large cost avoidance for exterior of buildings.

Abrasive blasting with chemical stabilizers is a cost effective alternative for removing lead-based paint from the outside surface of buildings. However, abrasive blasting can not be used on the inside surfaces of a building because of hazardous dust containment. Currently, environmentally acceptable chemical stripping costs about \$10 per square foot.

A decision tree has been developed, which is based on field demonstrations of emerging paint removal technologies, such as chemical stabilizers in blast media, sponge blasting, environmentally acceptable chemical strippers, carbon dioxide blasting, laser and xenon lamp assisted paint removal. This decision tree will assist in optimal selection of lead-based paint hazard control technology for a given application and result in large cost avoidance.

## **Family Housing and Child-Occupied Facilities**

In addition to lead hazard management in active Army housing, there are many costs associated with the transfer of Army properties. There are existing Federal regulations and a new Army guidance for lead hazard management for transfer of Army property through Base Realignment and Closure (BRAC) and other similar actions<sup>5,6</sup>. These regulations apply to pre-1978 properties intended for residential use after transfer. They require conducting lead risk assessments, disclosure of known lead-based paint and lead-based paint hazard, and abatement of hazardous levels of lead in paint, dust and soil.

Microwave assisted paint stripping is an economical alternative to chemical stripping inside of buildings and will result in a large cost avoidance when compared to chemical stripping. Recent tests supported by the Strategic Environmental Research and Development Program at USACERL indicate that the microwave assisted process is a viable solution to the problems of lead-based paint removal<sup>7</sup>. Microwaves have the unique ability to rapidly and selectively heat the coated surface. The microwave assisted removal process for lead-based paint from wood and composites was developed and patented at the U.S. Army Construction Engineering Research Laboratories by A. Kumar (U.S. Patent No. 5,268,548) and assigned to the Army. In the microwave assisted removal process, microwave coupling compounds (i.e., susceptors) are applied as a waterborne slurry or as a polymer binder paste to the painted surface. Susceptor materials, such as graphite or iron oxide can reach temperatures up to 1000°C in less than a minute when exposed to microwaves (800 watts). Activated polyaniline is advantageous as a susceptor in that it is a self-regulating material (i.e., loses conductivity as it is heated), thus reducing the fire hazard. The paint debonds from the substrate by heat from the microwaves, and is removed easily by scraping. Chemical stabilizing compounds, such as calcium silicate and phosphate, are applied to the susceptor prior to heating with microwaves. Following removal, the chemical stabilizers immobilize lead from the paint when mixed with water. The resulting waste is classified as non-hazardous, as can be verified by the EPA's Toxicity Characterization Leaching Procedure (TCLP). Two design approaches for the microwave paint removal system have been fabricated and used in the

laboratory to remove lead-based paint. The 1000-watt system developed by HVS Technologies, State College, PA, as shown in Figure 1, was designed to rapidly and uniformly heat a relatively small area. An alternate design for a microwave system was developed by USACERL in order to minimize arcing and potential damage to the wood substrate. In the USACERL system, which is shown in Figure 2, the microwave power is reduced, but applied over a larger area. A standard 1000 watt microwave generator, obtained from a household microwave oven, was modified to limit the power output to 300 Watts. The stub tuner in HVS design was replaced with a 20 dB gain horn, which applies the microwave power as it is scanned over a 6 in. X 6 in. area. The use of chemical stabilizers renders the waste non-hazardous by RCRA criteria.

A proof of principal field test of microwave paint stripping was performed on an Army building near Lexington Kentucky in December 1997. Both the HVS and CERL microwave system were used successfully to remove lead-based paint from an interior wood door and wood sill. Figure 3 shows photographs of a door inside the building, on which the microwave paint removal process was conducted. The lead levels on the wood were dramatically reduced on the areas stripped, with removal rates similar to those achieved in laboratory experiments. Laboratory studies are continuing in order to optimize the efficacy of the stabilizers and susceptors.

A lead-based paint risk assessment and hazard management system, called Painter-L, has been developed jointly by the Army and Navy. Painter-L tracks required information relating to the degree of lead hazards present and the remedial actions taken and provides a lead hazard management plan based on risk assessment and other data from dust wipes, paint samples and soil testing. Painter-L has the flexibility to accept data from previous inspections and assessments and import routines that are Navy and Army specific. The Lead Hazard Management Plan output by Painter-L provides information that is address specific, identifies hazard potentials and response priorities, presents lead hazard control options and on-going monitoring schedules. Painter-L tracks abatement projects by component, worker exposure by project and process, and inspector recertification, and provides a disclosure report that is compliant with the Title X Disclosure Rule.

Training of Army personnel is required by the EPA regulations. A software package which assists in hands on skills training (HOST) will reduce the time required for initial training as well as refresher training because part of the training can be given on site, thereby reducing travel costs. The system is designed to feature 6 modules. Each module is a 3-D interactive multi-media presentation that features narration, video, animation, text and graphics. The module for Collecting Lead Samples has been completed and contains 43 graphic screens including animation that walks the student through a typical residence. The advantages of the computer based instruction include: the user controls location, time, and frequency of training; lower cost; standardization of quality; and increased information retention.

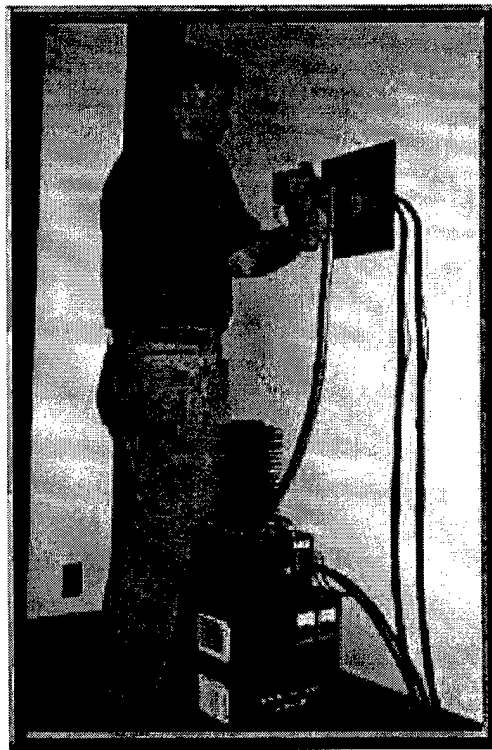


Figure 1. HVS System Microwave Applicator

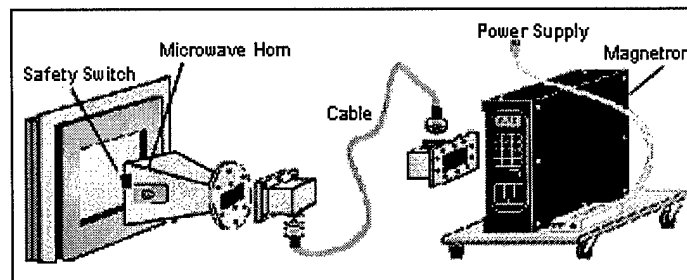
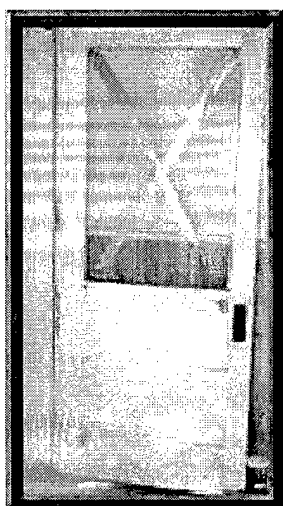
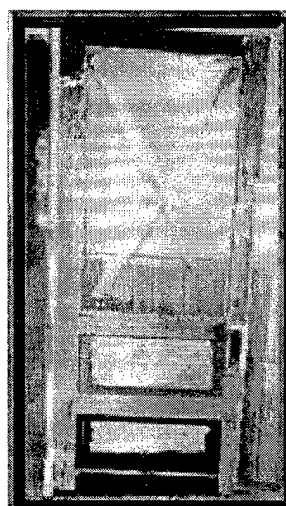


Figure 2. CERL Portable Microwave and Paint Removal System





A



B

Figure 3. Microwave Assisted Paint Removal from Door Inside an Army Building.

A—Prior to paint removal

B—After microwave stripping

## Summary

Lead-based paints (LBP) and primers have been used to protect steel structures from corrosion. Structures in the DoD that commonly contain lead-based paint include bridges, catwalks, towers, water storage tanks, steel doors, hangar doors, trusses, exterior railings, steel posts, poles, stairways, cranes, pontoons, boiler plant structural members and ship structures. The Army also owns approximately 90,000 facilities which most likely contain lead-based paint. The goal of the Army policy is to provide safe and healthful living and working environment. Cost effective procedures for risk assessment, interim controls, and abatement need to be provided to users for a lead hazard free environment.

Painter-L is a stand-alone computer based lead hazard management system that provides for the collection and analysis of risk assessment data, the development of installation lead hazard management plans, and establishes interim and long term lead hazard control strategies. It also facilitates management of hazards found and the remedial actions taken. The program can print the Disclosure of Information document as new tenants move in, disclosing the extent of any known lead hazard problems and what actions were taken to alleviate the problems. It also enables the collection of ancillary data for worker protection issues.

A computer based lead hazard risk assessment training module has also been developed. The purpose of the module is to train personnel who perform risk assessments, both initial and refresher training.

USACERL has demonstrated and evaluated emerging technologies for LBP hazard mitigation at Army installations. Technologies demonstrated and evaluated included abrasive blasting with chemical additives (e.g. Blastox™), which are designed to stabilize the waste generated by abrasive blasting lead-based coatings. Environmentally compatible chemical paint strippers have recently become available as replacements for more hazardous chemicals, such as sodium

hydroxide and methylene chloride. Alternate chemical strippers were evaluated in the laboratory for removing paint from wood and metallic substrates. One novel technology, patented by CERL, uses molten glass to remove LBP from steel structures. The thermal spray vitrification (TSV) process was successfully demonstrated on a steel bridge at Rock Island Arsenal in September 1997. Another technology patented by CERL uses microwave energy to remove lead based paint. The surface to be depainted is coated with a microwave coupling compound and then exposed to microwave energy which debonds the paint. The paint is then removed easily by scraping. Other technologies evaluated include sponge blasting, laser stripping, and carbon dioxide (CO<sub>2</sub>) blasting.

## Acknowledgement

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# **Field Demonstration of Multiple Bioslurry Treatment Technologies for Explosives-contaminated Soils**

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## **Abstract**

The U.S. Army Environmental Center field tested both aerobic/anoxic and anaerobic soil slurry biotreatment processes at Iowa Army Ammunition Plant to evaluate their performance and cost in remediation explosives contamination in soils. The trials were conducted in a RCRA quality lagoon and a concrete trench reactor, employing a variety of commercial impeller and hydraulic mixing systems. Test results described both degradation kinetics and metabolic fate, as well as the capabilities and limitations of different reactor configurations and mixing strategies. The demonstration was conducted in conjunction with a CERCLA removal action going on at the site, so excavated soils were treated at the test site, and the demonstration results will be used by environmental managers in their remedy selection.

## **Introduction**

The past production and handling of conventional munitions has resulted in explosives contamination (TNT, RDX, and HMX) of the soils at various military facilities. Depending upon the concentrations present, these explosives contaminated soils can pose both a reactivity and toxicity hazard, and a potential for groundwater contamination.

In 1995, the U.S. Army Environmental Center (USAEC) demonstrated the feasibility of soil slurry biotreatment as an alternative to incineration, using soils contaminated with explosives from the Joliet Army Ammunition Plant. The process involved suspending the contaminated soil in an aqueous slurry, and treating it in a reactor in which a co-substrate (molasses) was added to boost the metabolic activity of the microbial consortium native to the soil. Laboratory and the field pilot tests showed that operating the reactors in an aerobic/anoxic mode resulted in more complete degradation of TNT. The demonstration showed highly promising results, with the removal of TNT from about 1300 mg/kg to <10 mg/kg. In addition, RDX, HMX, and dinitro-toluene in the Joliet soil were also removed in the process to <20 mg/kg. Metabolic fate studies using radiolabeled TNT showed about 23% of the TNT was mineralized to carbon dioxide, with another 55% degraded to organic acids and carbon fragments in the biomass, indicating ring cleavage. Additionally, the microbial consortium functioned effectively with a wide range of soil concentrations, and in ambient temperatures down to 15-20°C. This provides a significant degree of flexibility in designing and operating systems to achieve treatment goals.

## Objective

To accelerate the fielding of bioslurry technology, the Department of Defense's Environmental Security Technology Certification Program sponsored the current study, which tested the aerobic/anoxic bioslurry process simultaneously with J.R. Simplot Company's Simplot Anaerobic Bioremediation Ex-situ (SABRE<sub>tm</sub>) process. The objective of the demonstration was to evaluate the performance and cost of soil slurry biotreatment as an alternative to incineration. The demonstration was conducted in conjunction with a Comprehensive Environmental Response Compensation and Liability Act removal action at Iowa Army Ammunition Plant (IAAAP), which hosted the demonstration.

## Materials and Methods

At Iowa, two types of bioslurry systems were evaluated: 1) The aerobic/anoxic process in a 55,000 gallon lagoon and 2) the SABRE<sub>tm</sub> process in a 10 to 12,000 gallon concrete trench. Cleanup standards were 196 mg/kg for TNT and 53 mg/kg for RDX.

Laboratory studies conducted in support of the field demonstration at Iowa showed that TNT and RDX could be removed from the soil to concentrations of less than 20 mg/kg in approximately 30-40 days. The design of the laboratory systems indicated that batch type processes were the most effective systems for use at Iowa.

The aerobic/anoxic lagoon system was designed to meet all Resource Conservation and Recovery Act standards, including a clay layer, dual high density polyethylene (HDPE) liners, and a leachate collection system. The lagoon was approximately 82' by 47' and included an appropriate two to one side slope for anchoring the liner system. The working depth ranged from five to six feet. No leachate was detected in the collection system. Figure 1 shows the reactor was designed to use off-the-shelf fan type mixers and a diffuser mounted on a traversing bridge. Although the bridge was designed primarily to support sampling throughout the reactor, its traveling mechanism also allowed for complete mixing and distribution of air. Approximately 55 to 60 cubic yards (yd<sup>3</sup>) of soil were added to the lagoon at the beginning of the demonstration. Water was added to the system to provide a soil slurry of approximately 40 percent by weight. Additionally, about 150 gallons of molasses was added to the system three times during the study.



Figure 1. Lagoon reactor with mixers on sampling gantry.

The SABRE<sub>tm</sub> system was tested in a concrete trench to utilize available mixing equipment without modifications for gantry width. The concrete trench was 50' long and 8'4" wide. The trench had an external HDPE liner and leachate collection system. It contained approximately 40 yd<sup>3</sup> of soil and water to generate a 40% soil

slurry. The system was operated by Simplot personnel and all additions were conducted by Simplot personnel. The proprietary amendments were added at the beginning of the process, based on the results of the laboratory treatability studies.

In both processes, explosives-contaminated soils and water are biologically treated in a reactor. Contaminated soils are excavated and screened to remove large rocks and debris that might interfere with mixers and pumps. In the reactor, mixers maximize mass transfer of the contaminant, and process controls for amendments, temperature, and aeration are designed to optimize the growth and activity of microbes which are capable of degrading explosives. The soils are mixed with water to produce a slurry that is typically 25 to 40% solids by weight. In both cases the additives, either molasses or the Simplot proprietary mixture, provide co-substrate and nutrients that are necessary for microbial growth and degradation of the explosives. This offers the potential for greater rates of degradation that can be seen with solid phase biotreatment processes. Reactor processes are also inherently flexible; it is theoretically possible to change the conditions of the reactor so that a treatment train alternative can be designed.

The biotreatment processes in both reactors were tracked intensively by sampling at ten locations in each reactor every week and analyzing for explosives and their degradation products using EPA method 8330. Other process variables, temperature, dissolved oxygen (DO), and redox potential, were monitored two or three times per week.

## Results and Discussion

**Aerobic/anoxic process.** As can be seen in Figure 2, TNT was reduced from 1500 mg/kg to below treatment levels in approximately eight weeks while limiting the accumulation of metabolic intermediates to less than 40 mg/kg. The temperature remained above 22°C, the DO fluctuated between 1.0 and 0 mg/L, and the redox potential of this system varied in the range of -50 to +50 mV, indicating the aerobic/anoxic nature of process. The variability in successive readings can be attributed to the characteristic heterogeneity of explosives in soil, and indicates the need for thorough mixing. The mixer pattern in the lagoon was altered by week seven; and following that, degradation of TNT proceeds in a timely fashion. Figure 2 also shows the degradation of HMX and RDX follows that of TNT, with much of the RDX removal generally occurring after that of TNT.

**SABRE<sub>tm</sub> process.** Figure 3 shows results from Simplot's SABRE<sub>tm</sub> process. It took approximately eight weeks for TNT to be removed in this operation. The temperature remained above 22°C, and the SABRE<sub>tm</sub> system maintained a redox potential generally less than -100 mV throughout the process. RDX was removed from the system after approximately 10 weeks, much of this occurring after TNT had been degraded. Process kinetics and degradation byproducts appear to be similar between the two processes.

**Further testing.** Currently, the treated slurry from both reactors are undergoing a variety of tests: radiolabeled TNT metabolic fate studies, leaching stability tests, plant growth analysis, and toxicity testing, including Ames assay and earthworm tests. Test results will be combined with the slurry sample analyses to determine the disposition of the treated slurry. Results from previous field trials indicate the slurry is suitable for direct land application.

**Slurry disposition.** The demonstration also evaluated options for disposing of the treated soil and process water, if land application is not an option. Slurry was gravity dewatered to 40% soil moisture in 2-3 weeks. Options for disposing of the

process water depend on discharge standards at the site. Residual explosives in the treated water were under the local National Pollutant Discharge Elimination System standards of 2 µg/L TNT, but the biotreatment processes in both reactors drove the biological oxygen demand (BOD) in the water above 10,000 mg/L. The results of analytical and toxicity tests can support land application of the process water. Otherwise, high BOD levels can require additional aerobic treatment or processing through activated carbon to bring it down to discharge levels.

**Design and cost.** Additionally, experience gained in operating these biotreatment processes has been applied to developing a conceptual engineering design for full scale treatment of Iowa's 10,000 yd<sup>3</sup> of explosives-contaminated soil. Both aerobic/anoxic and SABRE<sub>tm</sub> processes were incorporated as biotreatment alternatives, and the design included both aboveground tank and sunken lagoon reactor options. Cost projections from this design put the unit cost of bioslurry treatment around \$300-350 per yd<sup>3</sup>, in the same range as other biotreatment options such as windrow composting. This information was provided to the environmental managers at IAAAP for consideration in selection of a treatment process for their contaminated soil.

## Lessons Learned

1. Laboratory scale treatability studies are an important first step in determining whether site conditions will support biotreatment. Treatability studies can give the project planners the ability to estimate treatment periods before the project commences. The treatment times obtained from laboratory studies should be considered as estimates.
2. Mixing in rectangular lagoons requires additional operator time to handle dead spots. The mixing system used in this demonstration was theoretically oversized for the soil slurry. It still required extra attention to thoroughly mix material that contained 25-40% clay.
3. Removal of the slurry from the lagoon needs to be considered when locating the treatment system. Simply pumping the slurry from the reactor is effective for the majority of the contents, but a fraction remained that required mechanical removal.
4. The environment that this equipment must function is very extreme. Generally, acidic environments, low DO levels, and constant particle friction wear heavily on mixing and pumping equipment. Long term operations in these conditions require particular attention to be paid to equipment selection.

## Conclusions

Soil slurry systems have been successfully demonstrated in lagoon and trench configurations. The results indicate that TNT and RDX can be removed to standards that are necessary for the direct land application of soil. The bioslurry process is robust and may be adapted to operate in a relatively wide range of slurry concentrations and temperatures.

Process times and cost projections indicate that it is also a cost effective remediation option. Unit costs estimated for bioslurry treatment are at least half the cost of incineration, particularly for sites with less than 25,000-30,000 yd<sup>3</sup> of soil to treat. Based on experience from this field demonstration, the concept design

and cost estimates for full scale application of soil slurry biotreatment will be updated and published by USAEC later this year

## Acknowledgments

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# **Automated Soil-gas Monitoring during Biopile Operations**

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## **Abstract**

The On-Line Environmental Monitoring System (OEMS) developed by Battelle to automatically monitor oxygen, carbon dioxide, and total petroleum hydrocarbon (TPH) in soil gas was demonstrated at a biopile at the Marine Corps Air Ground Combat Center (MCAGCC) in Twentynine Palms, CA. The system operated over a 4-month period, sampling daily from 18 soil-gas monitoring points, 4 vapor-extraction galleries, and 2 blower exhausts. During this time period, the OEMS successfully functioned a total of 9,220 times while processing ambient air, calibration gas, biopile soil gas, and post soil-gas air flushing samples. The OEMS recorded changes in soil-gas constituents as the biopile was operated and facilitated making adjustments to optimize the aeration of the hydrocarbon-contaminated soil. It was shown during this demonstration that the OEMS technology can substitute for manual soil-gas sampling at remote sites, can be used in optimizing biopile performance, and could provide extensive databases during the evaluation of research aimed at investigating refinements of the biopile technology.

## **Introduction**

Bioremediation efforts generally have operational costs associated with manual soil-gas sampling for concentrations of oxygen ( $O_2$ ), carbon dioxide ( $CO_2$ ), and total petroleum hydrocarbons (TPH). In an effort to reduce these costs, Battelle has developed a remote monitoring system that automatically performs this sampling while using a suite of electronic sensors to quantitate both respiration and contaminant constituents in the vadose zone.

To permit automated sampling of soil gas at the Marine Corps Air Ground Combat Center (MCAGCC) biopile in Twentynine Palms, CA, the following components were used:

1. nine, bilevel soil-gas monitoring points (MP) were installed in the biopile,
2. the OEMS was mobilized to the site and installed in a field trailer,
3. monitoring point sampling modules (MPSMs), which are banks of solenoids enclosed in National Electrical Manufacturers Association boxes, were positioned close to the soil-gas monitoring points and each solenoid was connected to a specific sampling-point tube, and
4. an electrical cable and a 1/8-inch stainless steel sample transfer line were run



from each MPSM back to the OEMS so that solenoids could be opened and the soil gas transferred back to the monitor's sensors.

In the field trailer, a calibration gas cylinder was connected to a discrete sampling port on the OEMS and communications components were interfaced. The layout of this monitoring system is presented in Figure 1.

*(not furnished)*

Figure 1. OEMS Installation at the Biopile

During remote operation, the OEMS was automatically challenged with a commercially prepared (Matheson Gas Products, Twinsburg, Ohio) high-pressure cylinder gas standard at the beginning and end of each sampling event. This cylinder contained 4.92% O<sub>2</sub>, 10.03% CO<sub>2</sub>, and 508 ppmv TPH as hexane with nitrogen balance gas. The system was also programmed to sample ambient air, which contains 20.9% O<sub>2</sub>, 0.03% CO<sub>2</sub>, and non detectable TPH. Data from these samplings at the beginning and end of each sampling event permit the ongoing validation of each sensor's response. Slight drifting of a sensor's signal is accommodated for during data post-processing, when each sensor's response factor is calculated based on the calibration gas/ambient air sampling at the beginning and end of the soil-gas sampling event.

The OEMS employs a vacuum-assisted sampling train that pulls soil gas from monitoring points and delivers that gas sample to a common suite of sensors. The sampling process involves a series of timed and setpoint-driven events that make it possible to consistently deliver soil gas from a number of sampling points to the sensors. The OEMS sampling train is presented in Figure 2.

*(not furnished)*

Figure 2. OEMS Vacuum-Assisted Sampling Train

## **Biopile Facility at the MCAGCC**

The MCAGCC is an active military facility, located in the Mojave Desert in southcentral San Bernadino County, California about five miles north of downtown Twentynine Palms, which is about fifty miles north-northeast of Palm Springs. The site receives little rainfall and experiences a high evaporation rate. Near-surface soils consist of sands, gravels, silts, and clays, which originate from alluvial and playa deposits. Soils were contaminated at MCAGCC during field training exercises, maintenance operations, and surface and subsurface fuel storage operations. The petroleum-contaminated soils contain varying concentrations of JP-5 jet fuel, diesel fuel, and petroleum-based lubricants and oils. Contaminated soil has been excavated, transported, and stored at a designated staging area to await treatment. From this stockpile, a 2,500 yd<sup>3</sup> biopile was constructed at the permanent biopile facility located on Rifle Range Road on the Base.

The biopile facility consists of a concrete containment area that has 12 vapor-extraction galleries built into the floor of the pad. These galleries are connected to air-transfer manifolds, which in turn are connected to the vacuum side of 2 blowers. When soil is placed on the pile, the operating blowers generate a negative pressure at the base of the biopile that facilitates the movement of ambient air through the soil and provides oxygenated conditions for aerobic bioremediation to take place. The extraction galleries were fitted with sampling ports so that vapor extraction-gas samples (VES) could be collected and analyzed.

The biopile was constructed over a 4-day period from September 6 to 9, 1997. On September 17, 1997, the first of 2 blowers was started, initiating the bioremediation process. On October 30, 1997, a second blower was put online. To further enhance the movement of air through the biopile, on December 3, 1997, the gearing was modified on Blower #2 to double its airflow capacity. On December 24, 1997, the 2 blowers were shut down and a respiration test was performed. This respiration test continued through the end of the OEMS demonstration period on January 12, 1998.

## Results and Discussion

Following the installation of the OEMS, the first system performance test was to sample and analyze the high-pressure gas standard from each monitoring point. This was done to ensure that the sampling train could pull a representative sample from each point and to confirm that all fittings were leak tight. Tedlar<sup>tm</sup> gas-sampling bags (3-liter size) were filled with the calibration standard and then connected to the non-valved quick-connect fitting that would typically be connected to the upper soil-gas monitoring depth at each of the 9 bilevel monitoring points. This was also done at one of the VES points and the 2 blower exhaust sampling lines.

Data indicated that the OEMS was operating properly. The Tedlar<sup>tm</sup> bags deflated as the sample was being collected by the OEMS. Sensors provided both qualitative and quantitative data for each of the 3 constituents within 10% of the nominal concentration in the standard, confirming their operation. The consistent values also indicated that the sampling train was leak tight, since any leaks would have been reflected by elevated O<sub>2</sub> concentrations due to the influx of ambient air, and lower than expected levels for CO<sub>2</sub> and TPH, due to dilution with ambient air.

A second performance check of the O<sub>2</sub> and CO<sub>2</sub> data being generated by the OEMS was done through comparative analyses of biopile soil gas using 2 other techniques. First, the OEMS sampled soil gas from a monitoring point. Then a 1-liter megasyringe was used to pull soil gas from the same sampling point, and this soil gas was pushed into a Tedlar<sup>tm</sup> gas-sampling bag. From this sample, a measurement was made using a hand-held instrument (GasTech Model 3252OX O<sub>2</sub>/CO<sub>2</sub> analyzer) typically used for field analyses during respiration tests. The remaining gas sample was shipped to Battelle Columbus Laboratories for gas chromatographic (GC) analysis using a packed column with a thermal conductivity detector. The results of those analyses are presented in Figure 3.

*(not furnished)*

Figure 3. OEMS vs. GasTech vs. GC Data from Soil-Gas Monitoring Points at the Biopile

The coefficient of variance (CV) for O<sub>2</sub> measurements made by the OEMS and GasTech instruments did not exceed 5%. This would indicate that the OEMS and the hand-held field instrument generated similar data for this analyte. A greater degree of variability was observed between OEMS and GC data. For soil gas that was well aerated, the data agreed, with CV values for the 2 instruments as low as 0.2%. However, at MP-G where the O<sub>2</sub> concentration was reported by the OEMS at 16.6%, GC data indicated that the O<sub>2</sub> concentration was only 12.3%. This resulted in a CV, from the mean, of 14.8%. At the monitoring points where the

OEMS indicated no CO<sub>2</sub> was present (MP-C, MP-D, MP-E, and MP-F), there was agreement between the OEMS, the GasTech, and the GC techniques. The largest variance between the OEMS and GasTech was reported at MP-G, where there was a 0.9% difference in readings, corresponding to a CV from the mean of 3.8%. Again, the OEMS and the hand-held field instrument were generally in agreement with one another. However, this was not the case for the GC results. In each case, the GC data indicated that lower than OEMS-reported concentrations of CO<sub>2</sub> existed in the soil gas. This consistent discrepancy may be explained by looking at the calibration-gas sample GC results. It appears that a loss of CO<sub>2</sub> from the sampling bags occurred. The calibration gas contained 10.03% CO<sub>2</sub>, yet only 6.9% was indicated during the GC analysis of the Tedlar<sup>tm</sup> bag that had been filled with the mixture. This lower than expected response would imply that during storage and shipment, the CO<sub>2</sub> concentration decreased, and this was reflected in consistently lower levels being reported in the soil-gas samples when compared to the OEMS and GasTech data.

The results of this comparison between soil-gas data generated by the OEMS, a typical field instrument, and laboratory instrumentation indicate that the OEMS provides comparable data to the hand-held instrument generally used at bioremediation sites, but may provide somewhat different data from laboratory-level instrumentation. This is not totally unexpected, considering the sophistication and cost of GC systems and detectors, and the relatively inexpensive components in the OEMS. However, the test showed that the OEMS is fully capable of providing field screening quality data when automatically monitoring soil gas in a biopile for this demonstration, the OEMS operated from September 10, 1997 until January 12, 1998. Over these 127 days it was programmed to perform a total of 232 sampling events. A complete data set was not, however, achieved.

On November 23, 1997 there was a power outage at the MCAGCC that affected operations at the biopile. This loss of power shut down the biopile blowers and did not permit the OEMS to operate, since it relies on the 115 volt AC current to operate the vacuum pump and its 12-volt DC power supply. The real-time clock in the OEMS microprocessor is battery powered, so there was no interruption in this function. As a result, as soon as power was restored on November 24, 1997, the OEMS automatically picked up its sampling operations and went back on line. No previous data was lost because it was stored in nonvolatile memory. The loss of power resulted in no data being collected on November 23, 1997.

A second event occurred between December 31, 1997 and January 6, 1998 that resulted in data not being stored by the OEMS. During this time, the OEMS continued to sample as programmed, but the nonvolatile memory chip's storage capacity was exceeded. Consequently, data was being sent to the memory chip but was not being retained. To correct the problem that occurred at the biopile, the memory chip was cleared, the schedule for sampling was confirmed, and the OEMS once again went back on line saving data as programmed. Later versions of the OEMS now have memory chips that hold four times the amount of data as the system used at the biopile and software to further protect data storage.

Over the 127-day biopile monitoring demonstration, these were the only 2 problems encountered with the operation of the OEMS.

An example of soil-gas data collected by the OEMS is presented in Figure 4. These data reflect the changes in O<sub>2</sub> and CO<sub>2</sub> concentrations in soil-gas composition at monitoring point MP-B at the "high" or upper sampling depth.

Included on the figure are qualifiers that indicate mechanical changes made at the biopile that could have affected the concentrations of these gases.

*(not furnished)*

Figure 4. O<sub>2</sub> and CO<sub>2</sub> Measurement at Monitoring Point MP-B-H

Figure 4 shows that during the first 7 days of monitoring, CO<sub>2</sub> concentrations were increasing and O<sub>2</sub> levels were low. When Blower #1 was started, O<sub>2</sub> levels spiked, but then dropped again while the CO<sub>2</sub> levels continued to increase. This scenario generally indicates that the blower is not rapidly pulling ambient air past the monitoring point. However, soil gas was not stagnant since the CO<sub>2</sub> being generated in the biopile was increasing and was being pulled past the sampling point. Around the 35th day of operation, ambient air was beginning to affect this point. The increase in ambient air could have been due to air passages opening in the soil as moisture began to decrease. Adjustments were made to the valves that regulate the level of vacuum being pulled on various sections of the biopile soon after day 35. The adjustments initially produced an increase in the O<sub>2</sub> concentration, but whatever O<sub>2</sub> was pulled to this point was utilized and CO<sub>2</sub> was produced. At day 40, final adjustments were made, and after a lag time of about 4 days (indicated by 4 daily sampling event data points) ambient air was being delivered to soil at this monitoring point, as indicated by the increase in O<sub>2</sub> and decrease in CO<sub>2</sub> due to dilution. Delivery of ambient air was further enhanced on the 50th day when Blower #2 was started, and again on day 85 when Blower #2 was modified, doubling its air-moving capabilities. Following the power outage on day 73, it is suspected that soil-gas passages may have partially closed and this restriction resulted in O<sub>2</sub> utilization and CO<sub>2</sub> production. On day 109, the 2 blowers were shut down, and O<sub>2</sub> was utilized and CO<sub>2</sub> produced during the respiration test.

As shown in Figure 4, the OEMS did track the utilization of O<sub>2</sub> and the production of CO<sub>2</sub> during the shutdown test. Data from the OEMS provided the temporal monitoring necessary to determine O<sub>2</sub> utilization rates and calculate the biodegradation rates within the proximity of the monitoring points.

## Conclusions

As a result of this successful demonstration, the following statements can be made in regards to using the OEMS technology to monitor biopile activities:

1. The OEMS offers a cost-effective option for biopile monitoring. It is possible, with the system, to remotely determine if the biopile is operating and if the soil is being uniformly aerated. The microprocessor in the OEMS has the capability to trigger a relay to shut down the blower so that remote respiration tests could be performed. The blower could also be remotely restarted. Therefore, most manual activities, other than scheduled biopile component maintenance, could be performed by the OEMS.
2. The use of the OEMS could reduce the need for interim soil sampling. If data from respiration tests show that biodegradation rates are high, then it is likely that a hydrocarbon source still exists. When biodegradation rates drop off significantly, then soil sampling would be performed.

3. The OEMS would also be useful at permanent biopile facilities during initial operations to optimize the performance of the biopile. If a facility is constructed for the remediation of large quantities of soil, then multiple piles will probably be constructed. The OEMS can provide operational data for the initial piles that could be used to size and confirm blower selection and operation, to determine valve adjustments for directing airflow through the soil, and to identify general operating conditions that could then be applied to future biopiles. After operating conditions are identified for the soil type, contaminant concentrations, and facility optimization, then the level of data collection offered by the OEMS would not be necessary and some reduced manual effort would be adequate to assure that the biopile was being efficiently run.
4. Finally, the OEMS is a valuable research tool for further biopile technology development. Monitoring passive aeration, pulsed blower operation, or the effects of temperature, nutrients, and other amendments could be easily performed by the OEMS. The extensive databases that are possible with the OEMS to track cause-and-effect relationships would be economically impractical if done manually.

## Acknowledgments

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# **Low-Cost Disposable Hot Gas Decontamination System for Explosive-Contaminated Equipment and Facilities**

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## **Introduction**

For many years, the U.S. Army and other branches of the armed services engaged in a wide variety of activities involving the manufacture, handling, storage, testing, and disposal of explosive materials and chemical warfare agents. These activities resulted in the contamination of process-related equipment, piping, sewers, and enclosing structures with hazardous materials at various Department of Defense (DoD) installations. As a result, the DoD has numerous facilities and equipment at active installations, Formerly Used Defense Sites (FUDS), and Base Realignment and Closure (BRAC) installations which are contaminated with explosive residues and chemical warfare agents through historical manufacturing, transfer, storage, use and demilitarization of these materials. As part of its long-term environmental program, the DoD is required to decontaminate and remove explosive contamination from equipment and buildings at numerous DOD installations. Decontamination is required when equipment or facilities are placed in standby, transferred to another location, disposed of to other government or qualified private entities, or shutdown for maintenance, repairs, alterations, or modification. There is a particular incentive to do this at FUDS and BRAC sites where property transfer to private and public entities is the issue, and time is of this essence in many instances.

The DoD must identify, contain, and eliminate toxic and hazardous materials at facilities that are declared excess, and clean up these facilities and equipment to meet regulatory standards. This remedial action must be undertaken in a responsible and environmentally sound manner. Also, there is a current thrust within DoD to reclaim and recycle reusable materials and equipment whenever economically feasible as part of the "Resource Recovery and Recycle" (R3) trend.

Several types of facilities and equipment may be contaminated with explosives or explosive residue through the nature of their use, intended use, or exposure to explosive operations including:

- Munitions manufacturing plants
- Munitions demilitarization plants
- Munitions load, assemble and pack operations
- Explosives machining, casting and curing
- Laboratory testing facilities
- Explosive washout buildings
- Munitions storage igloos

Other areas where explosive-contaminated debris can be found include:

- Open burning and open detonation areas
- Range firing and target areas

Many types of contaminated building materials, process equipment, storage tanks, ton containers, spent shells, and debris may be found at these sites.

The standard methods for decontamination include open burning or incineration, or surficial cleaning by solvent wiping, pressure washing, or steam cleaning. Each of these methods has drawbacks related to ineffectiveness of surface cleaning, health and safety concerns, environmental prohibitions, and cost. The long-time historical decontamination method was to fill the building with combustible and flammable materials, and destroy the building and contaminants by open burning. This method is no longer acceptable at most locations due to air pollution control restrictions, and for health and safety reasons. Also, there is a desire to preserve buildings for reuse, and recycle equipment and scrap metal.

An environmentally-safe, non-destructive alternative is to decontaminate facilities using the Hot Gas Decontamination (HGD) technology developed by the U.S. Army Environmental Center (USAEC), formerly known as the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA). The HGD technology uses controlled heat to volatilize and thermally decompose the explosive contamination. The process was proven technically effective decontaminating explosive-contaminated equipment and facilities during several field demonstrations conducted by the USAEC. Successful full-scale field demonstrations were performed at Cornhusker Army Ammunition Plant (Nebraska), Hawthorne Army Depot (Nevada), and the Alabama Army Ammunition Plant. Also, the HGD process was proven effective in decontaminating chemical warfare-contaminated facilities in a pilot scale demonstration at Dugway Proving Ground (Utah) and a full-scale field demonstration at Rocky Mountain Arsenal (Colorado). Sampling and analysis for targeted contaminants (explosives or chemical agent) after HGD at these locations demonstrated that the process had decontaminated the contaminated areas to an analytically clean level. Decontamination efficiencies up to 99.9999% removal have been demonstrated using HGD technology.

During research and development (R&D), the HGD technology gained a reputation of being expensive. Costs incurred in these HGD projects included:

- R&D costs for a first time technology demonstration;
- Redundant safety and environmental systems;
- Testing and adjustment of operational variables during technology development;
- Additional instrumentation, controls, and monitoring required in an R&D setting; and
- Additional safety systems needed for chemical warfare agent destruction.

Now that the technical feasibility of the technology has been established, the USAEC is concentrating on lowering the cost for process implementation. The HGD technology has recently been further developed by USAEC to be economically competitive, environmentally sound, and technically superior to the alternatives. The lessons learned in previous technology demonstrations are the basis for the current low cost thrust.

The USAEC has prepared a design guidance manual which presents a standardized low-cost design for decontaminating and decommissioning explosive-contaminated facilities and equipment. The objective of the design guidance manual is to provide installation personnel with the necessary data to

make informed decisions regarding the practical application of HGD technology. The basic information required to develop a final design package that can be tailored to a specific installation for procurement, construction, operation (decontamination of facilities), and decommissioning is also provided.

## HGD Process Description

The HGD technology was developed by the U.S. Army Environmental Center (USAEC), Aberdeen Proving Ground, Maryland as an environmentally safe alternative to decontaminate equipment and facilities. The HGD process uses low temperature heat (500-600°F) to volatilize and decompose explosive residues in contaminated building materials and equipment which have been operational contaminated. Hot burner gas directly contacts the contaminated equipment or building materials to elevate the temperature of the medium. The effectiveness of the process is both time and temperature dependent. Holding times between 1 and 6 hours have been shown to be effective at the prescribed soak temperature. Previous demonstrations of the technology have proven it effective both *in situ* (Cornhusker, Nebraska and Rocky Mountain Arsenal, Colorado) and using a furnace (Hawthorne, Nevada and Alabama Army Ammunition Plant).

The Hot Gas Decontamination technology is effective decontaminating explosive contamination of the following explosives:

- 2,4,6-Trinitrotoluene (TNT)
- Ammonium Picrate (Yellow D)
- Research Department Explosives (RDX)
- Composition A-3 (RDX and wax)
- Composition B (TNT, RDX and wax)
- Tetryl
- Smokeless Powder (Nitrocellulose/Nitroglycerin)
- HBX (TNT, RDX, aluminum, lecithin, and wax)

The major advantage of the HGD process over surface decontamination methods (caustic or solvent washing, pressure washing or steam cleaning) is that it works in pores, cracks, crevices, and internal parts, as well as for surficial contamination. Up to 99.9% decontamination has been achieved by surface decontamination methods. Hot Gas decontamination however has achieved up to 99.9999% decontamination at previous demonstrations.

Volatilization is the primary decontamination mechanism, but some in-place decomposition also takes place. Because of the type and character of the constituents of the off-gas, the gaseous discharge from the process is contained, collected, and further treated to meet environmental regulatory requirements. At the previous full-scale demonstration of the process, a thermal oxidizer operating at 1800°F with a two-second retention time has been the standard off-gas treatment technology. The products of combustion at this temperature are primarily carbon dioxide and water.

The HGD technology is well-developed and supported by considerable research and demonstration. The U.S. Army Environmental Center (USAEC) began conducting bench-scale studies in the late 1970s to evaluate HGD technology for treatment of equipment, piping, metallic debris, and building materials contaminated with both explosive materials and chemical warfare agents. Successful pilot studies were followed by demonstration testing to define and refine the performance parameters. HGD technology is now available for field implementation and treatment of installations contaminated with explosive



materials or chemical warfare agents.

Process development and demonstration has defined the parameters for successful application of HGD technology. *In situ* HGD technology for treatment of equipment, piping, and facilities contaminated with explosive materials is most effective based on achieving 600°F for a minimum six hour soak period. Achieving these treatment parameters results in up to 99.999% removal of explosives contamination.

All of the previous demonstrations of the technology used an off-gas treatment system to treat volatilized emissions. However, as a one time decontamination action, the requirement for off-gas treatment is not an absolute. This can be demonstrated by recent permission by the Oregon Department of Environment Quality to open burn (flash flame) the Explosives Washout Building at Umatilla Chemical Depot, Umatilla Oregon without emissions control or treatment. The requirement for an off-gas treatment system must be evaluated on a case-by-case basis considering the site location and distance away from populated areas and off-site receptors, and local and state regulatory standards. Environmental permitting, emissions limitations, and monitoring (continuous or intermittent) requirements will be determined on a case-by-case basis. Use of emissions estimates, air modeling and fate and transport models can be used to make a case for HGD with no off-gas treatment. Operational controls (such as wind speed and direction restrictions) can be placed on the system to further promote the HGD system without off-gas treatment concept.

An off-gas treatment system with emissions monitoring significantly increases the cost, schedule, and complexity of the project. As a result, the lowest cost Hot Gas Decontamination system is one without an off-gas treatment, and this type system has been selected for the baseline here. A Process Flow Diagram is shown in Figure 1 (*not furnished*) which illustrates the general concept of the baseline low cost Hot Gas Decontamination (without Off-Gas Treatment). The system uses two recirculating-type gas burners to conserve heat and energy cost. The target area (the building or room containing equipment) is closed in to simulate a furnace for self-decontamination *in-situ*. To direct heat towards the greatest heat sink (the concrete floor), a thermal fabric blanket is lain over a steel frame to enclose the area or equipment to be treated. The building walls and floor form a chamber (target area) for containing the heated air. A high velocity recirculating air heater (similar to a home furnace) is used to heat the target area. Thermocouples with their accompanying temperature transmitters are interlocked to the air heater fuel supply to control the programmed soak temperature of the concrete, equipment, or building wall temperatures. A pressure transmitter may be interlocked to a motorized damper on the rigid portion of the exhaust stack to prevent over pressurization of the target area. After the 6-hour soak has been completed, a cool down period will be initiated by running the air heater fan with the gas burner off and the exhaust stack damper in the wide open position. This arrangement will force cooler ambient air through the target area.

A simple control process is employed for ease of operation and installation. Instrumentation is configured for remote read-out, with local read-out being used only for set-up and test. Any operational equipment or instrumentation placed within the target area must be able to operate at elevated temperatures. The number of thermocouples required will be based on the configuration of the site and shall be minimized. It is estimated that a maximum of 12 thermocouples will be required.

In the event that off-gas treatment is required by site conditions and regulatory requirements, a thermal oxidizer was used at each of the prior technology

demonstrations. A Process Flow Diagram for HGD with off-gas treatment is shown in Figure 2 (*not furnished*). A thermal oxidizer with an 1800°F temperature and 2 second residence time has been proven effective in previous technology demonstrations. The system design incorporates an afterburner to maintain a nominal negative pressure of 0.01 to 0.02 inches W.C. within the target area to ensure capture of volatilized contaminants. The off-gas system will generally have stack monitoring as a requirement. Regulatory requirements and design approval will dictate the final selection of design concept.

## Applicability of HGD Technology

The HGD process is applicable to explosive-contaminated equipment and buildings used in manufacture packing, packaging, storage, maintenance, preservation, renovation, and demilitarization of ammunition or explosives. Decontamination of these facilities and equipment must be undertaken in a safe, responsible and environmentally acceptable manner. As such, there are certain conditions for which the Hot Gas Decontamination system may not be applicable, or where additional safety or environmental controls must be implemented prior to application of the HGD process. This is the case when the application of heat on the order of 600°F or less may cause undue safety or environmental risk.

Some specific cases or conditions where this may occur (and the mitigating pretreatment measures to accommodate use of Hot Gas Decontamination) include:

- If a substantial amount of explosive material is confined in a vessel, pipe or other confined location, the explosive has a potential to detonate under heat with confinement. Equipment containing high levels of residual explosives (i.e., greater than 12 to 15 percent) present an explosive hazard and require special consideration. If such a scenario is encountered at a site being decontaminated, the equipment and confined explosive material must be cut out and removed before application of HGD process. Note that threaded pipe and joints in this situation should be cut out and not unthreaded, due to explosive hazard. Similarly, HGD of soil *in-situ* is not appropriate due to explosion potential caused by confinement of explosive in the soil.
- Friable asbestos should not be treated with the HGD process due to potential for dispersion of asbestos. Prior HGD process have been conducted with transite siding in building materials, with no adverse environmental effects. Friable asbestos must be removed according to regulatory requirements prior to application of Hot Gas technology.
- Hot Gas Decontamination is not appropriate for equipment or facilities with paint containing PCBs or lead. The PCB or lead in paint may volatilize. In this instance, PCB or lead-containing paint should be removed in accordance with applicable state and federal regulations. Similarly, PCB oil or PCB residue in vessels from prior spills must be properly removed or remediated prior to Hot gas Decontamination.
- Galvanized sheet metal, when heated above 700°F releases toxic vapor emissions. To use HGD in this case, the galvanized sheet metal must be insulated from the hot burner gas or temperature of the hot burner gas restricted to well below 700°F.
- Electrical wiring and wood are not appropriate materials for HGD and must be removed prior to initiating HGD.

- There is a public health risk associated with pigeon and other vermin droppings resulting in exposure of workers to bacterial virus. Such wastes must be properly removed prior to workers installing the HGD system.
- Broken windows require replacement or should be closed with fireboard prior to HGD.
- In some instances where gross contamination exists, facilities and equipment may require surface cleaning, and create a safe worker atmosphere for installation of the HGD system.

## Cost Information

An existing explosive washout facility was used as a model to develop equipment sizing and cost for a low-cost HGD system. A preliminary cost estimate is presented here for design, procurement, construction, operation, and decommissioning of a low-cost HGD system at the model facility.

Several features contribute to the technology's low cost and technical effectiveness including:

- A simple repeatable design;
- Use of locally available stock items, standard equipment, and expendables;
- Use of standard materials of construction;
- Simple control system and operation;
- Based on a one-time use and short project life;
- No R&D add-ons;
- Use of rental equipment where possible; and
- Minimum manpower and utility requirements.

Also, Hot Gas decontamination of equipment and structures *in-situ* eliminates the expense of tedious manual dismantlement by personnel in personal protective equipment.

The cost for the Baseline HGD system without Off-Gas Treatment is \$222,000 to decontaminate a 1200 square foot contaminated building (or room) containing contaminated equipment, or \$185 per square foot. The HGD system can be reused at an adjacent area for a large cost reduction due to economy of size. The cost for additional adjacent square footage at the same location is \$11 per square foot. For example, a 3600 square foot building can be decontaminated using HGD technology for \$249,000 or \$69 per square foot.

Similarly, the cost for the HGD system with the Off-Gas Treatment option is \$370,000 to decontaminate a 1200 square foot contaminated building (or room) containing contaminated equipment, or \$308 per square foot. Again, the system can be reused at an adjacent area for a large cost reduction. The cost for additional adjacent square footage at the same location is \$13 per square foot. For example, a 3600 square foot building can be decontaminated using HGD technology for \$400,000 or \$111 per square foot.

## Conclusions

*In situ* HGD technology has been developed as an acceptable and safe alternative to historical treatment methods for installations and the contained contaminated equipment and piping. The technology has been demonstrated in full scale at six locations. *In situ* HGD technology is a lower cost alternative to *ex situ* historical

treatment methods for contaminated equipment and materials, and reduces risks to personnel. The requirement for off-gas treatment of emissions greatly influences the cost of the HGD technology. In locations where off-gas treatment is not required by local and state regulatory standards considering the site location and distance away from populated areas and off-site receptors, HGD is extremely cost effective.

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# Natural Landfill Covers

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## Background

The Air Force has about 600 inactive landfills that require environmental remediation. There are also thousands of landfills with similar needs within the purview of the Department of Defense. These landfills typically cover large land areas and contain large volumes of waste. Because of the expense and risk associated with other methods of dealing with these wastes, they are usually contained in place. To contain the waste in a landfill, the primary action required is construction of a suitable cover, or cap.

## Characteristics of Military Landfills

Military landfills have characteristics that set them apart from common landfills in operation today. Over the years, virtually every military base has used landfills to dispose of wastes, including municipal waste, construction debris and rubble, industrial waste, cleaning solvents, paint strippers, and pesticides. The landfills at military bases are usually trenches, pits, or other depressions in the earth into which waste has been deposited. Whereas construction of most present day landfills includes a complex liner system to collect leachate and prevent leakage into the underground environment, most military landfills were built prior to the passage of the Resource Conservation and Recovery Act (RCRA) and do not have a bottom liner. During the 1980s, there was a shift from landfilling to contract waste disposal; as a result, the majority of military landfills have been unused for many years. Much of the waste in these inactive landfills has already consolidated and decomposed, so that surface subsidence of the cover will probably be small. Landfill gas production can also be expected to be low or nil; therefore, gas control may not be necessary in the cover design and significant cost savings might be realized.

The Air Force is currently responsible for nearly 600 landfills, and remediation is incomplete on about 61 percent of these. A recent survey has revealed the following characteristics:

- About 80 percent of the landfills have been inactive for more than 20 years.
- Less than 1 percent of the landfills have liners.
- The average size of a landfill is 13.3 acres.
- They contain primarily municipal solid waste.

## The Purpose of Landfill Covers

There are fundamental scientific and technical reasons for placing a cover on

landfill sites. Although regulations appear to drive the selection and design of landfill covers today, these regulations originated from specific environmental concerns and had technical foundations. While landfill covers offer many environmental benefits, three are preeminent:

- *Minimizing infiltration:* Water that percolates through the waste may dissolve contaminants and form leachate, which can pollute both soil and groundwater as it travels from the site.
- *Isolating wastes:* A cover over the wastes prevents direct contact with potential receptors at the surface.
- *Controlling landfill gases:* The release of explosive or toxic gases can create a potential hazard in the vicinity of a landfill.

These three principal benefits are common to all landfill cover designs although the way in which they are technically implemented can be quite different.

It is of interest to note that landfill covers are inherently intended to remain in place and provide protection to the environment for an extended period, perhaps centuries. However, experience with the most commonly used cover technologies extends only over about two decades. There is no way to predict with certainty how landfill cover performance will change over time, but innovative covers that do not rely on an "impermeable" barrier may offer more reliability in this respect.

## **Landfill Cover Design**

Over the past several decades, technologies have developed and advanced to enable the effective capping of landfills in accordance with environmental goals. At the same time, the process has become an expensive proposition and one largely driven by regulation. Ironically, regulations are sometimes blindly followed to the neglect of innovative technologies that can provide an environmentally responsible solution at considerable cost savings. Whereas the purposes of a landfill cover are clear, the particular implementation as translated into design elements is dependent on specific site characteristics.

## **Conventional Barrier Systems**

Nearly all landfill covers in place today are conventional, barrier-type landfill covers. Compacted clay and synthetic materials are common components in these barrier-type covers. These designs, which are often accepted as presumptive remedies, place a barrier layer within the cover that is intended to prevent water from moving downward in response to the force of gravity. In effect, these covers are designed to oppose the forces of nature.

## **The RCRA Landfill Cover**

Conventional covers employ barrier technology and typically include five layers above the waste (Figure 1). The top layer consists of cover soil that is typically 24 inches thick and supports a grass cover that provides wind- and water-erosion control. The second layer is a drainage layer designed to quickly remove any water that percolates through the cover soil and is stopped by the underlying barrier layer. The third layer consists of either a single low-permeability barrier or two or more barriers in combination; although this barrier layer is often referred to as an "impermeable" layer, no material commonly used as a barrier is truly impermeable when new, and most of them deteriorate with age. Compacted clay layers (CCLs) are the most commonly used barrier layers; they are typically about 24 inches thick and have a saturated hydraulic conductivity ( $K$ ) equal to or less than  $1 \times 10^{-7}$  cm/sec. Landfill covers with this feature are sometimes referred to as RCRA covers because they meet the requirements of RCRA Subtitle C. A gas-control layer is needed under the barrier layer to remove landfill gases before they can accumulate in harmful amounts. The bottom layer is a foundation layer of variable thickness and material; its purpose is to separate the waste from the cover and to establish sufficient gradient to promote rapid and complete surface drainage from the finished cover.

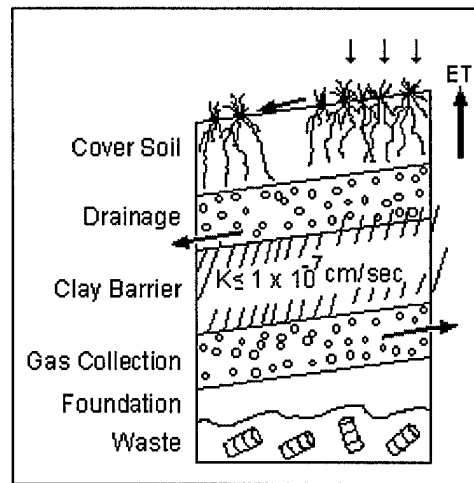


Figure 1. A typical barrier-type landfill cover.

## The RCRA Subtitle D Cover

The RCRA Subtitle D cover illustrated in Figure 2 meets the federal closure criteria for Municipal Solid Waste Landfills. This cover—which may also be called a compacted soil cover—is less expensive than conventional barrier-type covers and has been approved by regulators for use in dry climates. It includes a grass cover, topsoil layer, and a layer of undefined soil that is compacted to yield a  $K$  value of  $1 \times 10^{-5}$  cm/sec (Ankeny et al., 1997 and Warren et al., 1997). It is considered a barrier cover because it relies on compaction to create a layer of soil with reduced  $K$  value and the topsoil layer is commonly no more than 6 inches thick.

However, this type of cover does not ensure long-term protection against infiltration of precipitation into the waste because freezing and root activity are likely to increase the  $K$  value of the soil over time. There is no requirement for water-holding capacity within the soil cover. Therefore, after freezing and root activity loosen the soil, the cover may not control movement of precipitation into the waste if the plant-available soil water-holding capacity is low.

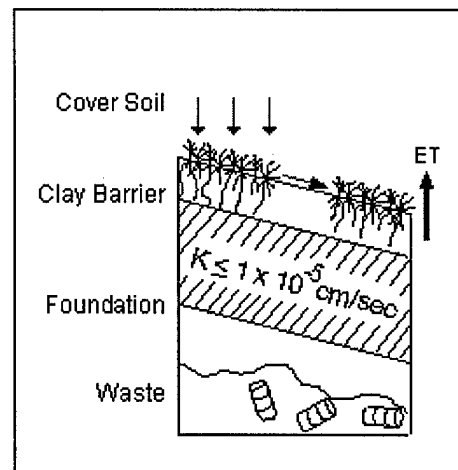


Figure 2. A RCRA Subtitle D cover.

## The Evapotranspiration (ET) Cover

The ET cover is a new concept that consists of a layer of soil covered by native grasses; it contains no barrier or impermeable layers. As Figure 3 illustrates, the ET cover uses two natural processes to control infiltration: (1) soil provides a water reservoir and (2) ET—natural evaporation from the soil plus plant transpiration—empties the soil water reservoir (Hauser et al., 1995; and Hauser et al., 1996). The ET cover is an inexpensive, practical, and easily maintained biological system that will remain effective over extended periods of time—perhaps centuries—at a low cost.

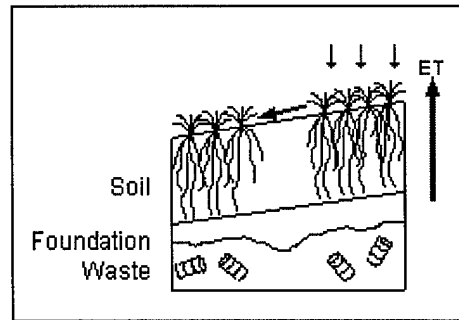


Figure 3. An ET Cover.

Climate is a primary determinant as to whether or not an ET cover is practical for a given site. The evaporation to precipitation ratio is naturally most favorable in arid and semi-arid areas. Hauser et al. (1994) surmised that properly designed ET covers could prevent infiltration into landfill wastes in most of the United States west of the Mississippi River and can minimize infiltration at numerous landfills in much of the rest of the country, as illustrated in Figure 4. The concept has the potential to work in humid areas also, but it must be evaluated on a site-specific basis.

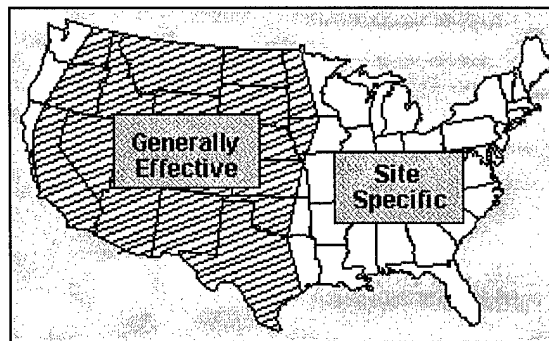


Figure 4. Regions where ET covers are effective.

Successful use of the ET cover requires good engineering design. The ET cover is different from other soil vegetative covers because it has the following minimum criteria:

- The soil physical properties must allow the most rapid and complete root growth possible for the plants growing on the cover. Good physical properties require a soil bulk density between 1.1 and 1.5 g/cm<sup>3</sup>.
- The plant-available soil water-holding capacity of the soil profile must be great enough to hold all soil water accumulated during critical design periods.
- The soil nutrient store and the plant-available nutrients should be adequate to support robust plant growth both immediately and for decades into the future via nutrient cycling within the ecosystem.
- The vegetation growing on the cover should be a mixture of grasses that are native to the site. Grass cover is specified because grass provides the optimum erosion control; however, for sites at which grasses are not the dominant native plants, the design should be modified appropriately.

The ET technology was developed and tested within the agricultural engineering and science professions. The principles of evapotranspiration were well understood years ago by hydrologists, plant and soil scientists, and agricultural engineers. Only in the last decade, however, has this knowledge been brought to bear on the problem of covering landfills and other wastes. Work by Anderson et



al. (1993), Hauser et al. (1994, 1995, and 1996), Nyhan et al. (1990), and Waugh et al. (1994) indicates that soil-vegetative landfill covers will prevent infiltration under appropriate site conditions. Proof of the long-term reliability of the ET cover concept is found in Aronovici (1971), Sala et al. (1992), and Lotspeich et al. (1971). Hauser and Chichester (1989) report the results of an intensive eight-year experiment with mine spoil covers that support the reliability of the concept. When properly designed, built, and maintained, the ET cover, can control or prevent movement of precipitation into stored wastes.

## Potential Cost Savings

Although landfill-cover design and construction has become a sophisticated operation, it is also very expensive. Typical costs for conventional covers on Air Force bases vary from \$380,000 to \$570,000 per acre; expenditures in the tens of millions of dollars for a single landfill are not uncommon. We conservatively estimate that the ET Cover can save \$150,000 per acre compared to conventional technologies. Of course, the appropriate landfill cover design is dependent on specific site characteristics, but there are perhaps 3,400 acres suited to the ET Cover at Air Force installations alone. That translates into potential savings of more than \$500 million.

## Summary

The Department of Defense should use the ET Cover where appropriate for the following reasons:

- It fulfills the purpose of covering landfills in two ways:
  - Minimizes water flow through the cover
  - Separates surface receptors from contaminants
- It has low construction cost
- It has low maintenance cost
- It is a natural self-renewing cover

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# **Cost-effective Sampling of Groundwater Monitoring Wells:**

## **A Data Review & Well Frequency Evaluation**

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## **Introduction**

Cost-Effective Sampling (CES) is a methodology for reviewing and assessing ground water data. The CES program produces a data information sheet and a lowest-frequency sampling schedule for a given groundwater monitoring location which will provides the needed information for regulatory and remedial decision-making. The data sheet indicates the activity of the compounds of concern and the sampling schedule is a recommendation list to be used as a tool to aid the project staff in decisions concerning sampling frequencies of the ground water monitoring and extraction wells. Its initial development at Lawrence Livermore National Laboratory (LLNL) was motivated by the preponderance of sampling results which showed little or no change in concentration over time or fell below detection limits in the 700+ groundwater monitoring wells at the laboratory's two environmental restoration sites. The fact that so many locations had shown very little change, or had ceased for some time to show, any detectable levels of contamination suggested that the 700+ groundwater monitoring wells were being sampled more often than necessary. The CES program was implemented at LLNL in 1992 and approved by EPA Region IX and the local regulators.

## **Locational vs. Data-oriented Sampling Rationales**

The original method for determining sampling frequencies at LLNL used the well location with respect to the contaminant plume (near or within a plume) as the deciding factor for the sampling schedule (see Figure 1). This decision process caused the majority of the wells to be sampled quarterly, even those that had shown no change over an eight year period. The major problem with this method was that it did not account for the slow rate of migration of the contaminants on the site. Because of the slow migration, concentrations within a well have tended to remain constant.

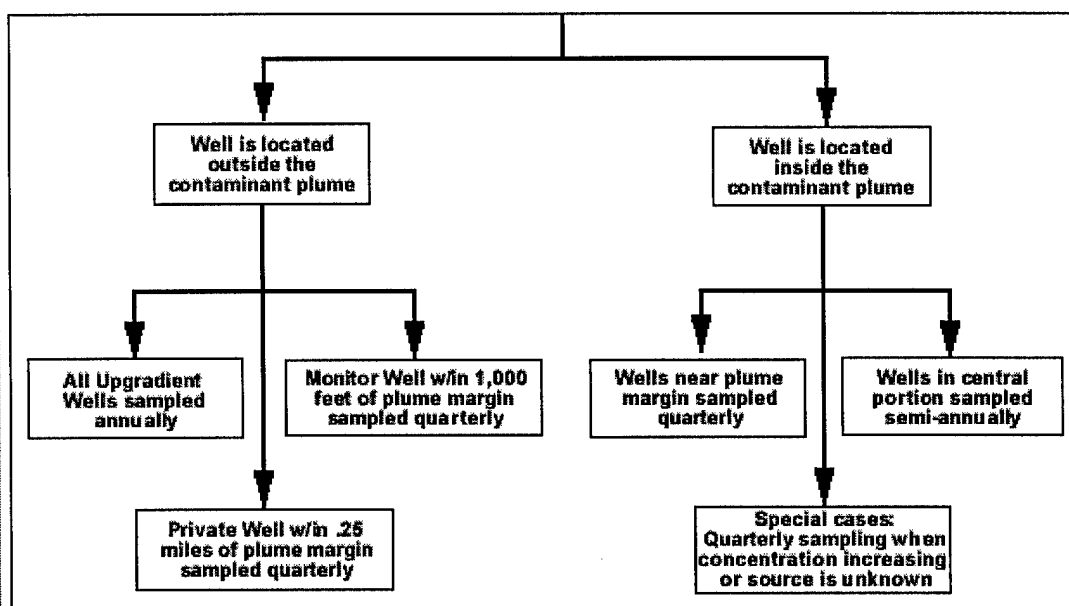


Figure 1. Location-Oriented Method of Setting Sampling Frequencies.

This intra-well consistency brought about the idea of basing the sampling frequency on the changes in concentration seen at a given well, rather than that well's location with respect to the plume. CES recommends sampling frequencies based on quantitative analyses of the trends in, and variability of, important contaminants at a given monitoring location. It then interprets this information by means of decision trees to arrive at a desired sampling frequency. An essential aspect of the system is its ease of interpretation. The goal has been to keep to widely-understood statistics that fit into decision-logic familiar to people involved with environmental chemistry.

The determination of sampling frequency for a given location is based on trend, variability, and magnitude statistics describing the contaminants at that location. The underlying principle is that a location's schedule should be primarily determined by the *rate of change* in concentrations that have been observed there in the recent past. The higher the rate of change, whether upward or downward, the greater the need for frequent sampling. Conversely, where little change is observed, a more relaxed schedule can be followed.

A second rationale for more frequent sampling is the *degree of uncertainty* displayed in the measured concentrations. Low overall rates of change can be offset by a higher degree of variability, requiring that a more frequent schedule be maintained to better define the likely degree of contamination at that location. On the other hand, a high rate of change that is highly predictable warrants a lower sampling frequency.

Finally, the *magnitude* of the measured concentrations affects the interpretation that is placed on rates of change. Clearly, a yearly change of 50 parts per billion (ppb) means something quite different when the median concentration is 10 vs. 1000. The significance of the absolute concentrations also varies by compound. The hazard associated with a 300 ppb concentration of TCE is interpreted differently from a 300 ppb concentration of chloroform.

A limited amount of statistical guidance is available for sites wishing to reduce their sampling schedules in a non-arbitrary manner. EPA documents written for RCRA facilities (U.S. EPA, 1992) suggest using techniques such as Darcy's Equation to

estimate the time between independent samples of groundwater based on the physics of flow. A second EPA publication presents a method for estimating sampling intervals from a combination of a first-order autoregressive model of groundwater time series data and the standard error of that series (Barcelona et al., 1989). A third, and especially interesting, approach is the creation of temporal variograms to estimate time correlations among samples in the same way that spatial variograms are used to estimate spatial correlations (Tuckfield, 1994). All the above approaches are geared toward determining the time-interval at which statistical independence is achieved. This is a key assumption to the proper application of standard significance tests and also provides a logical foundation on which to base sampling frequencies. However, these more purely statistical approaches to the sampling frequency problem have more difficulty gaining acceptance because of the highly specialized knowledge required to properly implement them. The goal of the joint venture between LLNL and SRS is to blend the practical, qualitative aspects of the early versions of CES with the firmer statistical foundations of the methods being examined at SRS.

## **Decision Logic Charts—Implemented Version**

A few issues must be clarified before proceeding to a discussion of the logic contained in the flow charts in Figures 2, 3, and 4. The first of these involves the available scheduling options. In the future, it is expected that fairly precise estimates of needed frequency, down to a resolution of weeks, will be made. This precision will become important when scheduling to assess the effects of remedial actions is incorporated into the system. For the time being, however, only compliance monitoring is being addressed. So, the scheduling options have been restricted to a multiple of the traditional quarterly sampling: quarterly, semi-annual, and annual.

Second, each scheduling category has been associated with a base rate of change. The annual category is reserved for trends of less than 10 ppb per year. The quarterly category is associated with rates of change in excess of 30 ppb per year. The semi-annual category falls in the range of 10-30 ppb per year. However, high and low degrees of variability can move a particular location out of the semi-annual and into the quarterly or annual categories. The currently used cut-offs have been tailored to 11 VOCs of particular interest at LLNL (Carbon Tetrachloride; Chloroform; 1,1-DCA; 1,2-DCA; 1,1-DCE; 1,2-DCE; Freon 113; PCE; 1,1,1-TCA; TCE; and Freon 11) and to the relatively low rates of change that are often seen at arid sites. In the version under development, a more generally applicable scheme for setting cut-offs is being employed.

The overall flow of CES is shown in Figure 2. To be eligible for consideration, a location (usually a groundwater monitoring well or piezometer) must have already been sampled on at least six occasions, which is roughly equivalent to 18 months of quarterly sampling. Newly installed wells must be sampled frequently to build up a history for the purposes of analysis. The decision-rules of the system are applied independently to each contaminant in the target list for a particular location. The schedule assigned to the location is the most frequent schedule estimated for any individual contaminant.

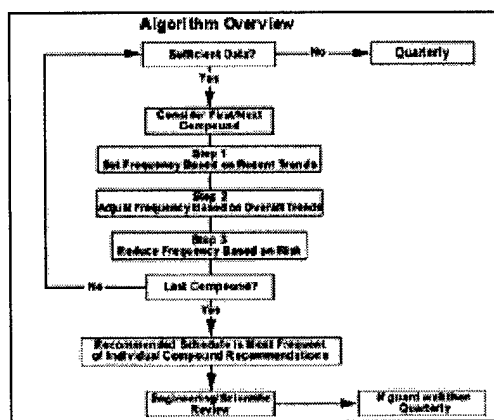


Figure 2. Overview of Steps in CES

The evaluation of each contaminant proceeds in three steps. First, an initial estimate of the desirable schedule is obtained by analyzing the most recent trend and variability information. In step 2, the recent trend is compared with the overall, or long-term trend, to identify cases where the step 1 decision should be overridden by an estimate based on overall statistics. In step 3, a correction is made for the less toxic substances on the list. Even though their yearly rates of change may be relatively high, their estimates are revised downward so long as the magnitude of the concentrations involved fall below certain limits. Finally, all CES recommendations are subject to change as a result of scientific and engineering review. Common reasons for overriding recommendations are anticipation of future remedial actions and public relations considerations pertaining to off-site locations.

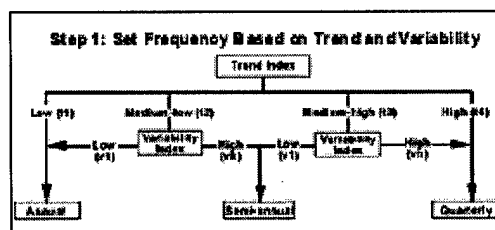


Figure 3. Step 1 Decision Logic

**Step 1:** As was mentioned earlier, the primary focus of CES is on trends or rates of change. This is currently defined as the least-squares slope obtained by regressing time against measured concentrations. The advantage of this statistic is its ease of interpretation. The slope can be expressed as a yearly change in concentration. Its disadvantage is that its suitability for use with non-normal data is questionable. Part of this problem could be solved by linearizing the data by means of a natural log transformation. However, this introduces interpretation problems which, for this first simple version of CES, we are trying to avoid.

Rate, rather than direction, of change is the dominant factor. All rate and rate-related statistics use absolute values. Based on the rate of change information, a location is routed along one of four paths (see Figure 3). The lowest rate, 0-10 ppb per year, always leads to an annual frequency schedule. The highest rate, 30+ ppb per year, always leads to a quarterly schedule. Rates of change in between these two extremes are qualified by variability information, with higher variability leading to a higher sampling frequency.

Variability is characterized by a distribution-free version of the coefficient of variation: the range divided by the median concentration. This statistic corrects for

the influence of magnitude on variability, which is an important consideration given that the range of concentrations in VOCs routinely varies over three orders of magnitude. The cut-off of 1.0 distinguishing high vs. low variability was derived empirically from the data distributions. It is the median value of that statistic calculated for the two most active contaminants at LLNL, TCE and PCE, across all locations in a benchmark dataset. Both the trend and variability statistics in Step 1 are calculated from the 6 most recent sampling periods worth of data.

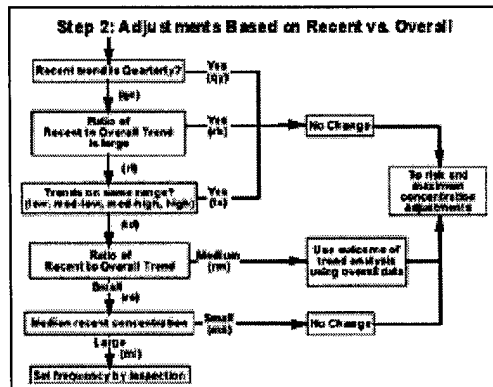


Figure 4. Step 2 of CES—Implemented Version

**Step 2.** While emphasis is placed on setting frequencies from recent data, there are cases where a long-term history of change may override the Step 1 decision. The first three boxes in the Step 2 flow chart (see Figure 4) weed out cases where such a re-evaluation is undesirable or trivial. The goal is to examine only those cases where the overall rate of change is significantly greater than the recent rate of change.

The major branch in Step 2 is meant to distinguish two ways in which the overall trend may be significantly greater than the recent trend. The right-hand side considers the majority of cases. The overall trend is definitely, but not extremely, greater than the recent trend: so the sampling frequency is re-estimated using Step 1 logic, but with overall rather than recent statistics.

The left-hand side considers the situation where the recent trend is very flat relative to the overall trend. If the flattening occurs at a low level of concentration, the Step 1 decision is retained. If not, the decision is left to scientific/engineering judgment.

**Step 3.** Not all compounds in the target list are equally harmful. Because of differences in drinking water standards, an average trend of 25 ppb/year for TCE is far more serious than the same trend for Chloroform or the two forms of Freon. So, quarterly and semi-annual decisions are reduced one level if the maximum concentration in the recent set of samples is less than 1/2 of the compound's MCL.

## Cost Savings—Implemented and Experimental Versions

The table below presents the sampling status of monitoring wells at LLNL's restoration sites both before and after the initial application of CES.

Sampling Schedule			
	Quarterly	Semi-annual	Annual
Before CES	418	112	24
After CES	216	124	214

It is estimated that this 40% reduction in the number of samples taken at the main site have saved \$390,000 annually in sampling, data management, and analysis costs.

## Acknowledgements

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# Landfill Closure Optimization

For  
Third Tri-Service Environmental Technology Workshop

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## 1.0 Introduction

Under the Remedial Action Contract with the Department of the Navy, Engineering Field Activity West (EFA-WEST), IT Corporation (IT) was awarded a delivery order to review and comment on the remedial design prepared by the Comprehensive Long-Term Environmental Action Navy (CLEAN) contractor, prepare workplans, and construct an engineered soil cap for the Site 2 landfill at Moffett Federal Airfield (Moffett), Sunnyvale California. Site 2 was used as a landfill from the 1940s to the early 1960s, and accepted primarily construction debris and household waste over an area of about 5 acres.

Closure of the Site 2 landfill, in accordance with the plans provided by the CLEAN contractor, was estimated by IT to cost \$1.3 million, including a two years of operation and maintenance. The plans included import material for the foundation of the cap, a geosynthetic barrier layer, protective soil cover layer, and topsoil layer. Concurrent with the work being performed by IT for the Site 2 landfill, the Navy asked IT to review and comment on plans and specifications for a second landfill cap for the 12-acre Site 1 landfill, located within one mile of Site 2 at Moffett. The cost estimate for the closure of the Site 1 landfill and the two years of operation and maintenance was \$2.2 million based on a preliminary landfill cover design provided IT. IT prepared a Value Engineered Alternative (VEA) report for the project, which included a technical approach and justification section, and a cost analysis. The VEA proposed excavating the Site 2 landfill and combining it with Site 1 landfill.

The VEA report presented figures showing the existing Site 1 landfill surface, the cover surface for the Site 1 closure, and the combined Site 1 and 2 closure cover surface. The VEA proposed to relocate Site 2 waste into Site 1 to make up a portion of the fill volume required to build up the elevation for the Site 1 cap. After the waste had been removed from Site 2, soil sampling would be performed to confirm that waste and affected soil had been removed. The site would then be backfilled and graded to drain. The VEA proposed a cap configuration to provide the landfill cover drainage for the combined Site 1 and Site 2 closure. The VEA also proposed the use of two sources of free borrow material for foundation soil, barrier soil, and protective cover soil consisting of soil from a bioremediation project at Moffett and dredge sediment from a nearby site in the City of Palo Alto.

The costs to combine the Site 2 waste into the Site 1 landfill and close the Site 1 landfill were provided in detail, and included two years operation and maintenance for both sites. The cost to complete the VEA alternative was estimated to be \$2.8 million compared to a cost of \$3.5 million for closing Sites 1 and 2 independently, resulting in a projected cost savings to the Navy of \$0.7 million. An added benefit of relocating the waste from Site 2 to Site 1 was that the land within the Site 2 footprint would become available for later development.

## **2.0 Design**

After the Navy and the regulatory agencies approved the VEA, IT took the lead in negotiating the design parameters for the Site 1 landfill cap and Site 2 landfill closure with the agencies. These agencies included the California Integrated Waste Management Board, the San Francisco Bay Regional Water Quality Control Board, and the Department of Toxic Substance Control. To expedite the regulatory review and approval, IT proposed that the Site 1 landfill design be modeled after local landfills, such as those of the cities of Sunnyvale and Mountain View. IT negotiated the methods to consolidate the Site 2 landfill into the Site 1 landfill, the concept of recycling groundwater from the Site 2 landfill for dust control at the Site 1 landfill, and the handling of hazardous waste if uncovered. IT also negotiated the quality control testing and material requirements for the landfill cap components and clay test pad.

The Site 1 landfill cross section consisted of a two foot foundation layer, a one foot low permeability clay layer, a geotextile biotic barrier layer, and a one foot vegetative cover layer. The foundation layer was partially constructed from contaminated soil that remained from a bioremediation project. IT located a free source of clay from an dredging excavation project being performed by the City of Palo Alto. The clay was certified by an independent consultant as being free of contaminants, and geotechnically suitable for constructing the cap. The clay material was used to construct the barrier layer and the vegetative cover layer. The cap was designed with an adjustable cover elevation to allow for an unknown quantity of waste to be incorporated from Site 2. The shape of the landfill surface was modified and designed to fit under the existing Federal Aviation Administration (FAA) mandated air flight control surfaces. The air flight control surfaces govern the maximum allowable height of all stationary objects within the vicinity of the runway.

The waste within Site 2 landfill was excavated and placed in the Site 1 landfill. The excavation surfaces were sampled and analyzed to determine if residual contamination existed. The regulators reviewed the analytical data and approved the Site 2 excavation for backfill. A free source of soil was obtained for backfilling this site. The site was graded to drain and hydroseeded. The agencies required one year of groundwater monitoring and, if no significant increases in groundwater constituents occur, the site would be considered clean closed.

## **3.0 Site 2 Construction**

Site mobilization took place immediately upon approval of project plans. The following preparatory activities were then performed at the Site 2 landfill, in anticipation of waste excavation:

- Clearing and grubbing;
- Underground utility location (including the location of a 36-inch diameter natural gas line);
- Overburden soil removal and stockpiling; and
- Groundwater and gas monitoring well abandonment (involving the removal of well casings and borehole pressure grouting).

Prior to excavating waste, exploratory trenches were excavated across the Site 2 landfill in order to dewater the excavation area (since most of the waste was situated within the influence of groundwater) and better define the nature and extent of waste. Approximately 1.5 million gallons of liquids were removed from

Site 2, during dewatering activities. Of this total, approximately 900,000 gallons were transferred to Site 1 for dust control and subgrade preparation. The remaining 600,000 gallons were discharged to the local municipal sanitary sewer after testing the liquids and obtaining the necessary permits.

After the exploratory trenches were completed and dewatering was substantially complete, the waste excavation phase of the project began. Approximately 23,000 cubic yards (cy) of waste were excavated from Site 2 and transferred to Site 1. The waste primarily consisted of industrial debris imbedded within a saturated soil matrix. Debris that was considered inert (i.e. glass, brick particles, and other construction debris) was left in place. A full time inspector was assigned to observe each bucket of waste excavated from Site 2, to assure that drums or other containers that possibly contained hazardous waste were set aside for further analysis and separate disposal.

The excavation extended to the edge of a road that bordered the north end of the Site 2 landfill. Measures were employed to protect the road, as well as underground electrical and communication lines that crossed the excavation. Particular caution was employed when excavating around a 36-inch diameter natural gas line that crossed the Site 2 landfill. As portions of the excavation were completed, as-built surveys were performed to document and quantify the extent of waste removal.

As waste excavation activities were nearing completion, soil confirmation samples were collected from the bottom and side walls of the excavation. A total of 37 samples were obtained and tested for subsequent comparison to Region IX Industrial Preliminary Remediation Goals (PRG) established by the United States Environmental Protection Agency. A 100-foot grid was implemented for the sampling (verified by IT's land surveyor) to assure proper distribution of sample locations. A few areas required additional excavation and retesting to meet PRGs.

The Site 2 area was backfilled with previously stockpiled overburden soils, and the surface was restored to achieve adequate cover and drainage. Backfill and cover soils were moisture conditioned and uniformly compacted in lifts to achieve adequate density. Approximately 9,000 cy of free cover soil were imported and placed within the Site 2 excavation. The two sources of soil used were from the light rail excavation project to the south of Moffett and the dredge sediment from the City of Palo Alto. The cover was graded to drain and hydroseeded for erosion protection. Finally, two groundwater monitoring wells were installed along the north perimeter of the site to verify clean closure of the Site 2 Landfill.

## **4.0 Site 1 Construction**

As Site 2 waste excavation began, construction activities were already underway at Site 1 to prepare the area for waste consolidation. The following preparatory activities were performed at the Site 1 Landfill:

- Clearing and grubbing;
- Underground utility location;
- The groundwater from Site 2 was transferred and dispersed over Site 1 for dust control and moisture conditioning;
- Subgrade proof rolling and the regrading of Site 1 waste to meet landfill closure design contours;
- Minor demolition, including the removal of an abandoned water system and manhole, and the removal of a portion of a pier that extended from the landfill into an adjacent stormwater retention pond; and

- Groundwater and gas monitoring well abandonment (involving the removal of well casings and borehole pressure grouting).

The waste that was excavated from Site 2 was consolidated at Site 1 to make up the *Lower Foundation Layer*. The waste was spread, graded, and compacted in lifts over the prepared subgrade. The primary challenge during consolidation activities was segregating and drying the wet waste in order to achieve suitable compaction conditions. Much of the waste required days of processing prior to consolidation.

The Site 1 and Site 2 waste was then covered with import soil to form the 12-inch thick *Upper Foundation Layer*. Approximately 30,000 yd<sup>3</sup> of soil from two free sources were used: the light rail project and soil from the bioremediation project. This upper foundation layer was spread, graded, and compacted in lifts to a minimum of 90% of the Modified Proctor maximum dry density.

The Site 1 landfill cover layers were then constructed over the prepared foundation layers. This cap consisted of the following components (from bottom to top): a 12-inch thick low permeability clay layer, a biotic barrier layer consisting of a 10 ounce per square yard (oz/yd<sup>2</sup>) nonwoven geotextile to deter rodent and root penetration, and a 12-inch thick vegetative cover layer.

The low permeability clay layer consisted entirely of soil from the dredging work conducted in the nearby City of Palo Alto. A *test pad* using the Palo Alto clay was constructed at the Site 1 landfill along one of the slopes of the cap to verify construction methods and determine necessary compaction criteria (moisture and density) for the clay. The performance criteria for this clay cap layer was a maximum hydraulic conductivity of  $1 \times 10^{-6}$  centimeters per second (cm/s). Approximately 38,000 cy of clay were spread, graded, and compacted in lifts (including the material placed at the perimeter road interface, which functions as the road subgrade). Because the source of clay was from bay dredging, particular effort was needed to dry the clay to a moisture content suitable for compaction. A separate staging area was established to moisture condition the clay prior to placement. During the construction of the low permeability clay layer, a groundwater extraction trench and gas venting trench were constructed along the perimeter of the landfill.

Once portions of the low permeability clay layer were complete, the clay was smooth rolled and covered with the biotic barrier geotextile. Approximately 500,000 square feet of geotextile material was placed to construct this layer. The 12-inch thick vegetative cover layer was placed concurrently with the biotic barrier layer, thereby eliminating the need to secure the geotextile fabric. Approximately 18,000 cy of soil were used to form the vegetative cover layer. To further reduce costs, several sources were used, including the light rail excavation project to the south of Moffett, the City of Palo Alto dredged clay, and several other nearby sources from the cities of Mountain View and Sunnyvale. The vegetative cover layer was compacted to a minimum of 85% of the Modified Proctor maximum dry density. The final surface was then graded to drain and hydroseeded to prevent excessive erosion.

A key factor in expediting the construction phase of this project was IT's close involvement with the Navy CLEAN contractor during the design phase, thereby enhancing the constructability of the design. Moreover, many design-related details were completed in the field, to accommodate specific site conditions during construction. As an example, the final contours of the Site 1 cap were modified by IT during the waste transfer from Site 2, since the expected quantity of Site 2

waste was uncertain. The resulting design had to accommodate all of the waste, while maintaining required drainage slopes and adequate clearance from the mandated air flight control surfaces.

## 5.0 Conclusion

The preliminary cost for combined closure based on conceptual designs was estimated by IT in July 1996 to be \$2.8 million. The actual cost for combined closure, as of November 1997 was \$3.1 million. Cost growths were the result of increased drying time of waste and soil due to unseasonably cool weather. The capital cost savings through landfill consolidation was estimated to be \$0.7 million, which included approximately \$0.4 million in disposal cost savings, since the bioremediation soil was used in the Site 1 foundation layer. More importantly, the operation and maintenance (O&M) period for the Site 2 landfill was reduced from 30 years to 2 years and seven acres of Site 2 are now available for later development. O&M costs were estimated to be approximately \$100,000 per year for the Site 2 landfill for a cost savings of \$3 million. The value of commercial property adjacent to Moffett is \$12 to \$20 per square foot, and the estimated value of the seven acres of Site 2 land is approximately \$4 million. Thus, IT's value engineered alternative produced over \$7 million in cost benefit to the Navy.

Landfill closure optimization includes many factors that need to be identified early. Facilities scheduling remedial investigations should be cognizant that consolidation is an option so that landfills are investigated concurrently. Facility environmental coordinators should approach regulatory agencies early to allow them time to confer with peers having previous experience. Planning for alternatives in the Record of Decision (ROD) allows flexibility during design and construction to utilize available and economical resources. Consolidation can be a viable alternative if a number of factors are present. These factors include: multiple landfills within close proximity (a few miles), teaming and *buy-in* with the facility management and regulatory agencies, early identification of potential opportunities in the investigative phase, and close coordination between the construction and design firms.

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# Hydraulic Oil Recycling

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## Introduction

The U.S. Army, in cooperation with industry, recently developed and demonstrated a methodology for returning used hydraulic fluid to vehicle service. The effort was conducted in three phases: First, a laboratory investigation to determine the viability of restoring used fluid to military performance specification. Second, a field investigation designed to identify commercially available equipment that could successfully process the used fluid and also demonstrate the performance of the restored fluid in military vehicles. Third, the Army entered into Cooperative Research & Development Agreements (CRADA's) with commercial companies that manufacture the certified hydraulic oil recyclers to test on-line diagnostics aimed at automating and optimizing the process.

Under the aegis of the aforementioned CRADA, industry developed technology that automates the process of restoring used fluid to "like new" condition. Testing and demonstration results indicate that the process of restoring used hydraulic fluid can be automated to require less labor and ensure complete restoration. This paper briefly explains the recommended process developed by the Fuels and Lubricants Team (formerly at Ft. Belvoir, now at U.S. Army Tank-automotive and Armaments Command, Warren, MI.) and presented in the "User's Guide For Recycling Military Hydraulic Fluid". Recent military hydraulic recycling programs, studies, and field demonstrations are discussed. The U.S. Army Environmental Center is supporting technology transfer by collecting important cost and performance information and hosting field demonstrations to potential users.

The on-site recycling of hydraulic fluid with a certified hydraulic oil recycler can have a significant impact on meeting pollution prevention goals. The benefits include reduced fluid disposal costs, reduced procurement costs for new fluid, and an uncomplicated avenue for conservation of natural resources. The implementation of hydraulic oil recycling throughout the U.S. military services will likely save millions of dollars per year.

## **Laboratory Investigation**

The approved methodology of recycling hydraulic fluids, developed jointly by the Army and industry, involves the removing of contaminants from the fluids and revitalizing fluid additives. Field investigations have shown that the most common reason for used hydraulic fluid being drained from vehicles and discarded is because it has become contaminated to such a degree that damage to the hydraulic system could result. Laboratory studies have determined that even though the hydraulic fluid may be heavily contaminated, its ability to perform has not been lessened. Analysis during the laboratory phase of this effort revealed that used MIL-H-46170 fluid (FRH) retained nearly all of its required performance capabilities, i.e. viscosity, corrosion protection, etc. The used fluid exhibited satisfactory performance in all but low temperature stability, water content, foaming characteristics, fire point, particle count, and evaporation loss. By removing the contaminants, laboratory studies have shown that the fluid properties can be restored to as good or better than MIL-specification requirements, except for the foaming characteristics.

It is essential that particulate and water contamination be removed from used fluid, because contamination can lead to premature wear as well as possible malfunction of hydraulic components. Particulate contamination has been shown to cause pump wear, valve spool sticking, seal wear, cylinder scoring, and erosion of system components. Particulate contamination can be removed from used hydraulic oil to prevent these problems and return the hydraulic fluid to its original performance specification levels.

Water can prove to be a very damaging contaminant in a hydraulic system. The presence of water can lead to decreased lubricity, viscosity, load-carrying ability, and dynamic film thickness; as well as cause acid formation. Free water in hydraulic systems that experience low temperatures (below the freezing point of water) can degrade system performance and cause malfunctions due to formation of ice crystals. Water contamination can be removed from used hydraulic fluid to prevent these actions and return the hydraulic fluid to specification performance levels.

During the laboratory testing phase, one concern was the occasional foaming of used hydraulic fluid. This can be attributed to the depletion of anti-foaming additives over long term use. It is this loss of foaming resistance in the fluid that prevents simple removal of contaminants from being the only treatment required to restore the used fluid to like new condition. In order to restore the used fluid to service, additional anti-foaming additive is required. Virgin hydraulic fluid contains less than 0.1% anti-foaming agent. Trying to blend very small amounts of additional additives into the used fluid outside a laboratory or manufacturing facility is not a viable technique for the soldier. Thus another solution was required in order to reuse waste hydraulic fluid. The Fuels and Lubricants Technology Team determined that the addition of new hydraulic fluid in the appropriate amount was sufficient to restore decontaminated, used fluid to specification performance. After an investigation into the optimum amount of new fluid to mix with used fluid, a mixture of 25% new fluid with used fluid freed of water and particulate contaminants exhibited satisfactory performance.

## **Field Investigation**

The second phase of the hydraulic oil recycling effort involved identifying and/or developing commercial technology that would satisfactorily remove the contaminants from the military hydraulic fluid, without altering the physical and

chemical properties of the reconditioned fluid. While a variety of technologies exist to clean up used oils in the commercial world, the Army's investigation revealed that not all of the technologies are appropriate to clean up military hydraulic fluid. MIL-H-46170 fluid in particular, poses an extra challenge in the removal of excess water. The fluid is formulated with an organic ester additive that has a strong propensity to absorb water. Commercially available fluid purifiers that depended strictly on special absorbent filters and/or coalescers typically were unsuccessful in removing the water from used military hydraulic fluid. In addition, the use of high heat may cause fluid oxidation, coking, or charring; high vacuum may strip the fluid of light ends, changing its viscosity; and desiccants may strip out fluid additives and add hard particulate contamination. These processes need to be avoided to maintain the physical and chemical properties of the fluid being recycled.

The Fuels and Lubricants Technologies Team entered into Cooperative Research and Development Agreements (CRADAs) with various companies to develop different processing units utilizing different technologies that were capable of removing water and particulate contaminants from the fluid at different throughput capacities. Once commercial units were identified and/or developed that successfully cleaned up the used fluid during laboratory testing, they were employed in a six month field demonstration to assess both the performance of the processing units themselves as well as monitor the performance of the hydraulic systems on the vehicles using the restored fluid. The results of the field demonstration highlighted the need to explore means of automating the process of recycling hydraulic fluid.

The field demonstration validated what had already been proven in the laboratory: used military hydraulic fluid can be processed such that it is restored to like new condition and successfully used in military vehicles. Experience with the recycling units, however, revealed that the process of recycling used fluid was somewhat cumbersome. The units available for use in the demonstration had no means of determining when the used fluid had been sufficiently processed to remove the water and particulate contaminants to below the MIL-spec levels. The only means available for determining when used fluid had been sufficiently processed was to collect and analyze samples for water content and particle count or to simply process the fluid for an extended period of time to ensure all contaminants were removed.

The method of determining the end point of the reconditioning process by collecting samples for analysis by a laboratory is both time consuming and labor intensive. In addition, if samples are collected too soon, the used fluid has to be processed an additional amount of time and samples collected and analyzed all over again. This increases the amount of time to the process particularly if there is no supporting laboratory on the installation and the samples have to be shipped to an off site laboratory. This extra time is accompanied by the cost of labor to perform the sampling and analysis.

The method of processing the used fluid for an extended period of time, although less costly than sampling and analysis, poses additional risks. Because the processed fluid is not analyzed for water content and particle count, there is no means of determining when the fluid has been cleaned sufficiently. To overcome this uncertainty, the fluid must be processed for an extended period of time, even though it is likely that the fluid is cleaned long before the time has elapsed. Much of the used fluid processed during the field demonstration was adequately cleaned in less than three hours, but a significant margin of error must be built into the processing time unless on-line diagnostics are available.



The solution is to automate the certified processing units such that the recycling units perform in-line analysis and a "go/no-go" indication is given to the operator. Two of the vendors that participated in the field demonstration phase entered into CRADAs with the Fuels and Lubricants Technology Team to accomplish in-line fluid condition monitoring on a recycling unit. The challenge was to incorporate affordable technology into the processing unit without impeding processing unit performance.

## Automated Sensor Development

To date, one company, Pall Aeropower Corporation, has successfully developed affordable technology married to the processing units to provide the in-line diagnostics needed. The technology employed in the Pall Automated Hydraulic Fluid Recycling Unit (depicted in Figure 1) removes particulate contamination consistently, based on the number of passes of fluid that the system sees. The water contamination removal rate is dependent on a number of factors including oil type, temperature, water content, ambient humidity, etc. Because the Pall recycling unit particulate removal rate is consistent and predictable and typically the particulate contaminants are removed long before all of the water is removed, Pall Aeropower Corporation opted to incorporate a water sensor into its recycling unit as a means of detecting water content of the fluid. After a time delay, set to ensure particulate clean-up, the automation package interrogates the water sensor to determine when the relative humidity level of the fluid being reconditioned drops to a level corresponding to less than 500 PPM water (for MIL-H-46170, other fluids are set for the specific MIL-spec). Once all of the criteria are met, the recycler shuts off automatically.

Pall's purifier, with its water sensor and automation package, provides an automated hydraulic oil recycling unit that makes the process consistent, repeatable, and economical in terms of time and labor required. The automation package is set at the factory for a specific hydraulic oil. By following the procedures developed by the US Army, and using a certified automated recycler, the recycling process can be accomplished automatically. The Pall Aeropower Corporation water sensor and automation package senses the relative humidity (% solubility) and temperature of the fluid being purified, and converts this information into a PPM measurement. The automation package uses this information to shut the recycler off when the fluid being recycled is cleaner and drier than the MIL-spec requirements.

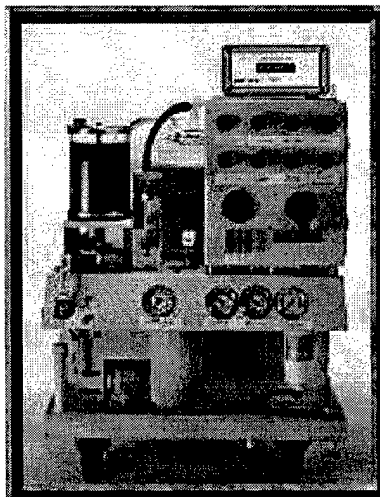


Figure 1  
Pall Automated Hydraulic Recycling Unit

## Contamination Removal Process

The Pall Automated Hydraulic Fluid Recycling Unit utilizes a proven technology that Pall has been providing to the U.S. Military since 1965. The current purifier incorporated in the recycler includes the latest improvements, while keeping the system simple to use and safe to operate. The purifier employs spinning disk, mass transfer dehydration, and high efficiency/high dirt capacity membrane filtration technologies, which are processes that effectively remove the contaminants while not degrading the hydraulic fluid.

The detailed removal process is as follows (see Figure 2 for flow schematic): Contaminated hydraulic oil is drawn into the vacuum chamber through a mesh strainer. A float valve regulates the inlet flow, keeping it equal to the output of the discharge pump. The oil entering the vacuum chamber impinges on the center of a spinning disk. As the disk rotates, oil flows outward to the edge of the disk, progressively decreasing in film thickness. The oil is thrown off of the disk and breaks into very small droplets yielding a large surface area for the oil. Maximizing the surface area of the oil directly increases the water removal rate.

Ambient air is drawn into the vacuum chamber through an air breather filter. The air expands to approximately five times its former volume, resulting in an 80% reduction in relative humidity. The dry air is passed over the contaminated oil droplets and the water, air, and solvent contamination is transferred to the air stream from the oil. The water, air, and solvent contamination are carried from the vacuum chamber within the air stream exhaust.

The dehydrated and deaerated hydraulic oil from the vacuum chamber is pumped through a proprietary, synthetic media, 3-micron absolute non-bypass filter. This filter removes particulate contamination quickly and effectively, while exhibiting an extremely high dirt holding capacity. The purified hydraulic oil exits the purifier, returning it to a storage container, system reservoir, or application.

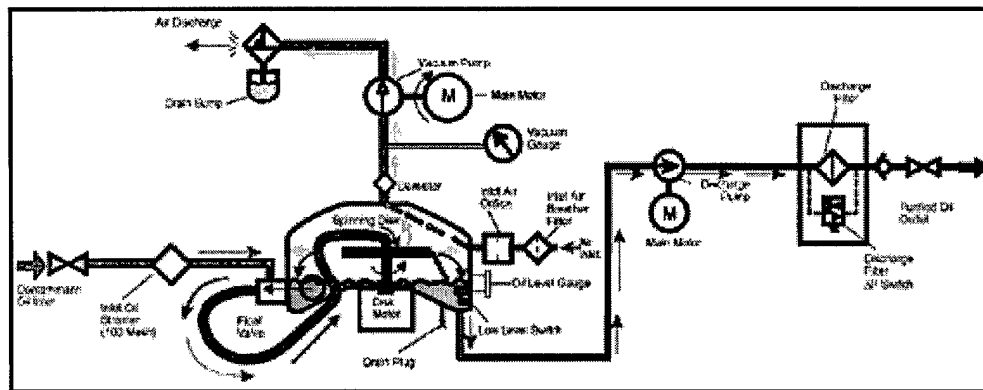


Figure 2  
Pall Purification Process  
Flow Schematic

## Recent Implementation Programs

The U.S. Air Force has been evaluating the Pall Automated Hydraulic Fluid Recycling Unit for use on aircraft. The Airbase and Environmental Technology Division (AFRL/MLQ - Tyndall Air Force Base, Florida), initial investigations provided the impetus for a Memorandum for Record (MFR) released in October

1995. This MFR concluded that the Pall unit purified new and used hydraulic fluids without degrading their working properties. The MFR recommended a hydraulic pump wear study, which is ongoing under the auspices of the Air Force Research Laboratory Nonstructural Materials Branch (AFRL/MLBT) at Wright-Patterson Air Force Base, Ohio. The initial pump wear test was conducted with MIL-H-5606; with the results indicating that the highly purified fluid (with the gentle process of the Pall unit) did not adversely affect pump life/performance. A second pump wear test is underway, looking at MIL-H-83282. The AFRL/MLQ has estimated that the successful implementation of the hydraulic oil recycling program could save the U.S. Air Force \$30 million a year.

In addition, the U.S. Air Force Air Mobility Command is conducting an operational utility evaluation with the Pall automated hydraulic oil recycling unit at McChord AFB. This testing is being carried out to verify the feasibility of recycling hydraulic fluids for reuse on aircraft, using MIL-H-83282, MIL-H-87257, and MIL-H-5606. After the above studies are completed, it is expected that these fluids will be added to the approved recycling list for the military.

The U.S. Navy Environmental Leadership Program (NELP) investigated purifier systems for removing contaminants from aircraft hydraulic fluid. This study was accomplished at the Aircraft Intermediate Maintenance Department (AIMD) at Naval Air Station North Island and Naval Station Mayport. The NELP study concluded that purifying hydraulic fluid will provide a major environmental benefit by reducing the volume of waste fluid with a corresponding decrease in the requirement for new fluid. Information on these tests is available on the Internet via the Tri-Services Pollution Prevention Technical Library (maintained by the Naval Facilities Engineering Services Center) listed as Recycler, Hydraulic Purifier. Additional information can be found in the Pollution Prevention Equipment list (maintained by the Navy Office of the Chief of Naval Operations {N45}) and directly on the Pall website at: [www.pall.com/envirosolutions](http://www.pall.com/envirosolutions).

The U.S. Army Environmental Center is supporting technology transfer by collecting important cost and performance information and hosting field demonstrations. A Pall Automated Hydraulic Fluid Recycling Unit was sent to Ft. Irwin to field verify the cost and performance evaluation. The Ft. Irwin data will give a worst case scenario, due to the extreme dust and sand conditions and high vehicle usage rates that are experienced there. The typical procurement cost of MIL-H-46170 (FRH) is \$10.00 per gallon. Disposal costs vary greatly from near \$0.00 to over \$3.00 per gallon. The cost to recycle the FRH is roughly \$3.00 per gallon depending on site conditions, fluid contamination, and available workforce. The Pall unit is now approved by the Army and is commercially available. Due to the reasonable cost of the recycling unit, the recycling of hydraulic oil has the potential for a very short payback period with a great deal of long-term cost savings.

## Conclusions

- The use of a certified automated hydraulic oil recycler, incorporating in-line monitoring technology, optimizes processing time and eliminates the labor required to collect and analyze fluid samples.
- Recycling hydraulic fluid to specification performance means less new fluid must be kept in stock to meet fluid usage requirements.
- Recycling hydraulic fluid reduces the amount of used fluid which must be

disposed of.

- Recycling hydraulic fluid has the potential for very substantial dollar savings throughout the Department of Defense.
- The approved recycling process works consistently and is easily repeatable.
- The implementation of hydraulic oil recycling throughout the U.S. Military will have a significant impact on meeting pollution prevention goals, conserving natural resources, and reducing costs associated with both the procurement of new and disposal of used hydraulic fluids.

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# Demonstration of In-Well Aeration Technology

(aka, Groundwater Circulation Wells)

## Introduction

The Air Force Center for Environmental Excellence (AFCEE), in response to a Broad Agency Announcement proposal submitted by Wasatch Environmental Inc. (Wasatch), conducted a demonstration of an in-well aeration technology called density-driven convection (DDC) at Keesler AFB MS. The technology, also known as Groundwater Circulation Well (GCW) technology, underwent a two-phase demonstration involving a pilot study and large-scale demonstration between 1995-1997.

## Description of DDC In-well Aeration Technology

DDC is a patented GCW technology developed by Wasatch in which the well casing is screened across two intervals. Typically, the upper screen is installed across the water table and the lower screen is installed near the bottom of the aquifer interval to be treated. Figure 1 shows a typical DDC well.

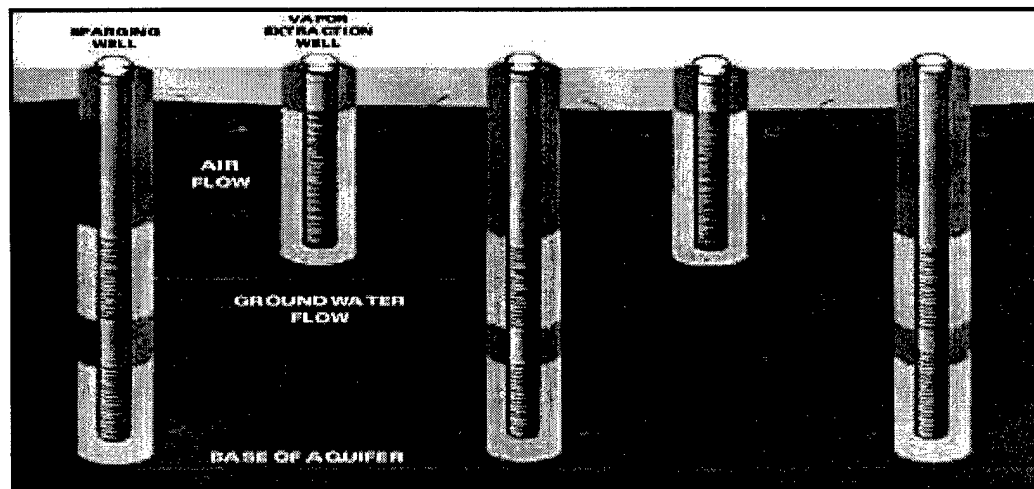


Figure 1. Typical DDC Wells with associated SVE System

As air is injected through a central pipe in the lower portion of the DDC well, it rises in a series of slugs which pushes water upward within the well, much the same as air lift pumping. The water level rise in the upper portion of the DDC well causes water to flow out the upper screen back into the aquifer. Air mixed with water reduces the density of the saturated column within the well, resulting in a reduction in the hydraulic pressure at the bottom of the well. The outward flow of water at the top and reduction of hydraulic pressure at the bottom of the well produce a circulation of water in the aquifer around the well.

Two mechanisms are responsible for remediation of groundwater and soil: 1) volatile compounds are stripped from groundwater flowing through the well; and 2) bioremediation in the soil and groundwater is enhanced as oxygenated groundwater flows out of and away from the DDC well. Bioremediation in the

vadose zone soils can also occur as oxygen is introduced via the upper screen into surrounding soils. The technology can also increase the dissolution of sorbed contaminants in the soil, as the groundwater effluent from the DDC well flows through the aquifer matrix where partitioning can occur.

## **Background**

Keesler AFB is located in Biloxi, Mississippi, approximately 80 miles east of New Orleans, Louisiana. Keesler AFB comprises 1,494 acres of federally owned land. The base was activated in June 1941 as a training center for aircraft mechanics and continues to operate as a training center for the Air Force.

## **Demonstration Site**

The BX Service Station served as the demonstration site at Keesler AFB. A site map is presented as Figure 2. The station is currently active with three (3) 20,000 gallon underground storage tanks (USTs). Site topography is flat with an average elevation of approximately 20 feet above mean sea level.

Previous site investigations included a bioventing pilot study as part of the AFCEE Bioventing Initiative in May 1993. Six bioventing wells (three extraction and three injection wells) were installed in the same area as the current field demonstration. Average TPH concentrations in vadose zone soils were reduced by 78 percent and average TPH concentrations in soil gas were reduced by 89 percent. (Battelle, 1995).

## **Site Conditions**

Soils across the demonstration site consist of silty sand to a depth of about 3-4 feet, and fine to medium grained, poorly graded sand to a depth of 22 feet. Clay was encountered at a depth of about 22 feet. The demonstration was conducted in a shallow, unconfined aquifer. Groundwater occurs at approximately 7 to 8 feet below the ground surface. Groundwater flows east or northeast under a horizontal hydraulic gradient of 0.004 to 0.005 ft/ft. Horizontal and vertical hydraulic conductivities measured during the pilot study were 32 ft/day and 9.5 ft/day, respectively.

The source of contamination in the soil and groundwater was gasoline and diesel leaked from earlier USTs and dispensers. TPH concentrations up to 21,000 ppm were detected at 7 feet bgs, and 9900 ppm at 9 feet bgs. Concentrations below 9 feet quickly tailed off. Based on results of sampling conducted during the installation, Wasatch estimated the mass of petroleum hydrocarbons in the subsurface at approximately 45,000 pounds. Previous investigations suggested that the areal extent of impacted groundwater was approximately 130,000 square feet. The groundwater plume reportedly extended approximately 400 feet down gradient of the site. Baseline groundwater conditions for the demonstration were established based on results of groundwater sampling at the start of the pilot demonstration.

## **Phase I—Pilot Study**

The Phase I pilot study was conducted over a 19-day period beginning April 18, 1995. The principal objective of the pilot study was to develop design parameters for the application of DDC at this site. The pilot study involved a variety of activities to measure the groundwater circulation rate, flow pattern, and stripping

efficiency of a DDC well. It also included activities to measure the radius of influence and hydrocarbon removal efficiency of a SVE well. Results of the pilot study were used in the design of the large scale DDC system under Phase II of the demonstration.

### **Phase I Pilot System Description**

The pilot study system included installation and operation of one SVE well and one DDC well. Seven (7) piezometer pairs and seven (7) dual-level soil gas monitoring points were installed to monitor DDC well operations. The locations of the pilot study wells and monitoring points are shown on Figure 2.

Soil gas monitoring points were installed in a line running north (SN1, SN2, and SN3) and south (SC1, SS1, SS2, and SS3) from the SVE well. Each monitoring point had two (2) probes constructed of stainless steel pipe with 6-inch screens. One screen was installed to about 4 feet the other to about 6 feet deep. Two probes were installed to evaluate the effects of SVE and DDC on soil gas at different depths.

The DDC well was installed approximately 8 feet south of the SVE well. It was constructed of 4-inch diameter PVC with screened intervals from 4 to 14 feet and 16.5 to 21.5 feet below the ground surface. Screens on the well consisted of 0.02-inch factory slots spaced 0.125 inches apart. One piezometer pair was installed in the DDC well boring with screened intervals near the upper and lower screened intervals of the DDC well. The lower piezometer (SWD) was screened from about 18 to 19 feet and the upper piezometer (SWS) was screened from about 9 to 10 feet below the ground surface. Piezometers SWD and SWS provided sampling points for water inflow to and outflow from the DDC well.

Six (6) piezometer pairs were installed in lines running east (PE1, PE2, and PE3) and south (PS1, PS2, and PS3) from the DDC well at radial distances of approximately 10, 20, and 40 feet. The piezometer pairs were installed to provide monitoring points for piezometric elevation, and sampling points for groundwater chemistry and dye concentrations. The paired arrangement provides comparison of these parameters between the upper and lower portions of the aquifer.

*(not furnished)*

Figure 2. BX Gas Station and Pilot Study Layout

### **SVE Tests**

The radius of influence of the SVE well was evaluated by installing vacuum gauges on each of the soil gas monitoring points and measuring the pressure response while applying a vacuum to the SVE well. For this test, the radius of influence was defined as the distance to 1 percent of the vacuum pressure applied to the SVE well. Results of the test showed a radius of influence of approximately 60 feet.

The baseline average oxygen and carbon dioxide concentration was approximately 7 percent and 7.3 percent, respectively. Average concentrations of oxygen and carbon dioxide during the test were 17.4 and 2.6 percent, respectively.

### **DDC Tests**

The radius of influence of the DDC well was evaluated by two methods: 1)

injecting dye into the DDC well and monitoring its movement through the aquifer; and 2) measuring for hydraulic gradients within the piezometer pairs. The rate of groundwater flow through the DDC well was approximately 4 gpm.

A fluorescent dye (Rhodamine WT) was injected into the DDC well at the start of the test. Groundwater samples collected from piezometers showed dye migrated 10 feet from the DDC well within two days of system startup and 20 feet within six days of system startup. Migration in the down-gradient direction (east) was higher than the cross-gradient direction (south) based on the concentrations of dye observed.

Operation of the DDC well produces a downward vertical gradient within the aquifer. The gradient is apparent as differences in water levels in the piezometer pairs and declines with distance from the DDC well. Baseline monitoring showed no vertical gradient in the piezometer pairs before starting the DDC system. However, once started, the gradient measured in the piezometer pair installed in the DDC well boring averaged about 3.3 feet throughout the pilot test. Gradients up to 0.3 feet and 0.04 feet were measured in piezometer pairs PE1 and PS1 (10 feet) and PE2 and PS2 (20 feet). No gradient was measured in piezometer pairs PE3 and PS3, about 40 feet from the DDC well. According to Wasatch, this indicated the radius of influence the DDC well at this site could approach at least 20 feet.

The stripping efficiency of the DDC well was evaluated by analyzing groundwater samples collected from piezometers SWD and SWS and calculated as the difference in TPH and BTEXN concentrations between inflow and outflow, divided by the inflow concentration. Stripping efficiencies averaged 95 percent for TPH during the pilot demonstration. The stripping efficiencies for individual aromatic hydrocarbons also averaged over 90 percent except benzene, which averaged 76 percent.

The hydrocarbon concentration in the inflow samples increased over time. This is believed to be due to the mechanics of vertical groundwater circulation created by DDC, which drew dissolved hydrocarbons downward toward the lower screens of the DDC well increasing the inflow concentrations.

After completion of the pilot tests in May 1995, a decision was made to allow the DDC system to remain in operation unattended. The system operated for an unknown period of time before stopping due to blower failure. Inspection of the pilot test blower showed it had failed due to wear. The impact of this decision would not be apparent until later.

## **Phase II—Large Scale Demonstration**

Phase II of the demonstration involved installing and operating a large scale DDC system. The objective was to demonstrate the effectiveness of DDC in promoting in situ bioremediation and in-well stripping.

### **System Description**

Phase II involved the installation and operation of a large-scale system consisting of 6 SVE wells and 32 DDC wells. The location of the large-scale system wells is shown in Figure 3. DDC wells were installed south and east of building 1504, in the area of highest soil and groundwater contamination. The DDC wells were constructed similar to the pilot DDC well. DDC well spacing was based on the radius of influence determined in the pilot demonstration. One positive pressure



blower supplied air to 12 DDC wells, and a larger blower supplied 20 DDC wells (Figure 3).

*(not furnished)*

Figure 3. Large Scale DDC System Construction

### **Large Scale SVE System Operation**

The 6 SVE wells included 4-inch diameter casings installed to 7 feet and screened 2-7 feet below the ground surface. SVE wells were installed to prevent vapor migration into the building and draw oxygen from the DDC wells into vadose zone soils. A single vacuum blower was used for the SVE system. Emission samples were analyzed for total petroleum hydrocarbons (TPH) and the individual aromatic hydrocarbons: benzene, toluene, ethylbenzene, total xylenes, and naphthalene (BTEXN).

SVE emissions showed concentrations of carbon dioxide decreased from approximately 3 percent to 1 percent, while oxygen concentrations increased slightly from approximately 19 percent to 20 percent. After 533 days of operation, Wasatch estimated the mass of TPH removed at the SVE effluent was approximately 3,449 pounds. This included 3,090 pounds removed by direct volatilization, and 359 pounds removed by biodegradation. Calculations of mass removal due to biodegradation were based on differences between concentrations of oxygen and carbon dioxide in the effluent and atmospheric air. The calculations assumed all oxygen consumption and carbon dioxide production were the result of biodegradation of hydrocarbons. Mass removal calculations are summarized in Table 1.

*(not furnished)*

Table 1. Estimated TPH Mass Removal by SVE

### **Large Scale DDC System Operation**

Large scale DDC system monitoring included measuring groundwater field parameters and collecting groundwater samples for chemical analysis. The field parameters measured include groundwater elevations and dissolved oxygen (DO) concentrations. Monitoring also included collecting soil samples for chemical analysis three times during the demonstration.

### **Groundwater Elevations**

Groundwater elevations were measured in piezometer pairs to evaluate the gradient produced by DDC operation (Table 2). The downward vertical gradient produced by operation of the DDC system is evident in the elevation differences between the shallow and deep piezometers. Biofouling in the DDC well casings may reduce groundwater circulation. The convergence of elevations of the three monitoring points in August 1997 (461 days of operation) was likely due to biomass buildup (biofouling) in the DDC well and piezometer casings. The DDC wells and piezometer casings were redeveloped and the gradient between SWS and SWD were again apparent at 533 days or October 1997. The water table at the site fluctuates seasonally reaching a high point during the late summer months and a low during the early winter. The groundwater elevation fluctuated nearly 1.4 feet (downward) during the demonstration from a high at the start of the demonstration.

(not furnished)

Table 2. Water Table Elevations

### Dissolved Oxygen (DO) Concentrations

The highest DO concentrations were measured in SWS, as expected due to its proximity to the DDC well's upper effluent screen. Table 3 shows DO concentrations over the demonstration. The averages were calculated without including data from SWS or SWD. As seen in Table 3, DO concentrations remained depleted throughout the site except at SWS. This was probably due to the high biological oxygen demand existing at the DDC well effluent (upper screen) where most of the contamination was located. As a result, oxygen was quickly utilized near the well as an electron acceptor during biodegradation of dissolved petroleum hydrocarbons and other abiotic reactions occurring in the aquifer. Elevated DO in the deep piezometers in the latter period of the demonstration may be due to increased flow of oxygenated water in the lower portion of the aquifer. The buildup of biomass described above may also have reduced the permeability in the shallow portion of the aquifer and directed some of the water flowing from the DDC wells downward in a short-circuiting mode.

(not furnished)

Table 3. Dissolved Oxygen Concentrations

### Groundwater Chemistry

Groundwater samples were collected from the wells listed in Table 4. The concentration of TPH in groundwater was evaluated for both on-site (PE3-S and MW11) and down-gradient (MW8-3 and MW8-4) monitoring wells. Average TPH and total BTEXN concentrations for the on-site and down-gradient monitoring wells are presented in Figures 4 and 5, respectively.

(not furnished)

Figure 4. Average On-Site Concentrations

(not furnished)

Figure 5. Average Off-Site Concentrations

The average TPH concentration in the on-site monitoring wells seen in Figure 4 decreased over time, except for one concentration spike measured after approximately 70 days of operation. Average BTEXN concentration increased during the first 200 days of operation and then began to decrease. The initial increase in dissolved concentrations is believed to have resulted from the circulation of groundwater and subsequent desorption of hydrocarbons from soil. The average TPH concentration in the on-site monitoring wells decreased 87 percent from 51.4 ppm to 6.50 ppm while the average BTEXN concentration decreased 91 percent from 4.80 ppm to 0.420 ppm.

As evident in Figure 5, a TPH and BTEXN concentration spike appeared after 100 days of operation in the down-gradient monitoring wells. After approximately 230 days concentrations fell below initial levels. Subsequently, the average TPH concentration in the down-gradient wells decreased 13 percent from 20.3 ppm to 17.6 ppm, while the average BTEXN concentration increased 12 percent from 8.55 ppm to 9.55 ppm. The TPH and BTEXN spike appearing down-gradient was probably due to incomplete groundwater capture by the large-scale DDC system.

As the DDC effluent was introduced above the shallow, contaminated 7-9 foot zone of the aquifer, the concentrations increased due to dissolution of sorbed contaminants. Incomplete capture of the now contaminate-rich plume would explain why the concentrations increased down-gradient, outside the radius of influence of the DDC well system.

*(not furnished)*

Table 4. TPH and BTEXN Concentrations

### Soil Chemistry

Soil samples were collected from three borings drilled within the treatment area to evaluate the soil conditions and remedial monitoring. Approximate locations of the borings are shown in Figure 3. Samples were collected in April 1996 during installation of the large scale system installation established baseline soil conditions. Comparison samples were collected in April and October 1997 from borings drilled near the original borings. Soil samples were collected at depths corresponding to the vadose zone (5 feet), immediately above the water table (7 feet), and at three intervals below the water table.

The highest initial TPH concentration (21,000 ppm) was found in boring B3 at the water table. The highest initial TPH concentration in saturated zone soils was 9,900 ppm in a sample collected from boring B1 at about 9 feet below grade. The initial sample collected from the same depth in boring B2 contained 8,800 ppm TPH. The highest TPH concentration in deeper soil (11 to 15 feet deep) was 440 ppm in a sample collected from boring B1 at 15 feet deep. The initial sample collected from boring B1 at 19 feet deep contained 35 ppm TPH. The sampling showed a similar distribution of BTEXN in the site soils. TPH concentrations in the shallow vadose zone confirmed the effect of the bioventing pilot study conducted in May 1993.

TPH and BTEXN concentrations throughout the site dropped, generally, better than 10-fold during the demonstration. Average TPH and BTEXN in the capillary fringe decreased approximately 98 percent during the demonstration. Average TPH and BTEXN concentrations immediately below the water table (9 to 10 feet) decreased approximately 35 and 52 percent, respectively, during the same time. Average TPH and BTEXN concentrations in samples collected from 11 to 15 feet deep decreased approximately 55 and 87 percent, respectively. (Figure 6)

*(not furnished)*

Figure 6. Average Soil TPH Reductions

### DDC In-Well Stripping Efficiency

The stripping efficiency of the DDC well averaged 68 percent based on data collected between June 1996 and April 1997. After that date, samples were either not collected due to biofouling of piezometers, or no hydrocarbons detected in the samples. However, the 68 percent value includes one sample event in which the inflow and outflow samples had identical concentrations of dissolved constituents resulting in a calculated stripping efficiency of zero for that event. Identical concentrations in these samples suggest the possibility of sampling or analytical error. Excluding these data, yields an average stripping efficiency of approximately 79.5 percent, and standard deviation of 21.8 percent. This value seems reasonable when compared with the stripping efficiency demonstrated in the

pilot study.

## Mass Removal Due to DDC Operation

Calculation of the hydrocarbon mass removal due to operation of the DDC wells was completed based on the operation and monitoring results described above. The following assumptions to calculate the mass removed:

1. groundwater flow rate measured during the pilot study is representative of all the DDC wells.
2. average stripping efficiency of the pilot DDC well is representative of all of the DDC wells.
3. average DO concentration in the inflow and outflow of the pilot DDC well are representative of all DDC wells.
4. concentration of dissolved hydrocarbons in the inflow of the DDC wells was equal to the average TPH in three on-site monitoring points (SWD, PE3-S, and MW11). MW11 is screened across the aquifer and samples from it are assumed to represent the average of the entire aquifer. The concentration in SWD would be expected to be lower than in other parts of the study area due to operation of the pilot DDC well after the pilot study and to its location farthest from and cross-gradient of the source. Thus, the concentration of PE3-S averaged with SWD is also assumed to be a conservative estimate of the average concentrations across the aquifer.

Results of the mass removal calculations are summarized in Table 5. According to these results in-well stripping accounted for most of the TPH removed with estimated removal rates of up to 2.4 pounds per day per well. Calculated biodegradation rates show a TPH mass removal of approximately 0.1 pounds per day per well. The cumulative TPH removal values were corrected to account for the part time operation of the larger pressure blower during the early part of the demonstration. Results of the calculations show that the large scale DDC system affected the removal of approximately 15,767 pounds of TPH during the demonstration.

*(not furnished)*

Table 5. TPH Mass Removal from all DDC Wells

## Summary and Conclusions

The Phase I pilot study provided information on aquifer properties and design parameters for DDC wells. Results showed an SVE well at the demonstration site had a radius of influence of approximately 60 feet. DDC wells appeared to produce a radius of influence of at least 20 feet with a water flow rate of approximately 4 gpm. Phase II of the field demonstration provided an opportunity to apply design parameters developed in Phase I and to evaluate the remedial efficiency of DDC in-well aeration.

Phase II results showed the SVE system removed approximately 3,090 pounds of TPH through direct volatilization. Oxygen and carbon dioxide emissions from the SVE system showed biodegradation in the vadose zone resulted in removal of approximately 359 pounds of TPH. Increasing oxygen concentrations in the SVE emissions was likely due to air drawn through the vadose zone from the DDC

wells.

The ability of the large scale DDC system to affect groundwater flow was apparent in vertical gradients in the piezometers. The stripping efficiency of DDC wells was shown to average approximately 79 percent over the course of the demonstration. In-well stripping accounted for approximately 90 percent of the 15,767 pounds of TPH removed from the groundwater during the demonstration.

Overall, the large scale DDC and SVE demonstration systems removed approximately 19,216 pounds of TPH in 533 days of operation. It has produced reductions of 97 and 36 percent in the capillary fringe and saturated soil TPH concentrations, respectively. Average TPH concentrations in groundwater within the treatment zone were reduced 87 percent. By comparison, average TPH concentrations in down-gradient wells showed no significant reductions.

## **An Air Force Perspective**

While the Technology Transfer Division at the Air Force Center for Environmental Excellence (AFCEE/ERT) sees positive results from application of GCW technology, some important considerations and concerns are also worth mentioning.

As with all environmental remedial technologies, GCW technology carries certain application risks. For example, lack of circulation cell development in a GCW system could result in spreading of contaminants in previously uncontaminated areas of the aquifer. This could result from two factors: 1) poor in-well treatment or stripping efficiency and the resulting introduction of effluent into clean portions of the aquifer, and 2) desorption of soil contaminants from the effluent wash not circulating back to the influent screen for (re) treatment and instead escaping down gradient (Parsons Engineering Science 1997).

As evident in Figure 5, a TPH and BTEXN concentration spike appeared after 100 days of operation in the down-gradient monitoring wells. The spike was probably due to incomplete groundwater capture by the large-scale DDC system. As the DDC effluent was introduced above the shallow, contaminated 7-9 foot zone of the aquifer, the concentrations increased due to dissolution of sorbed contaminants. Incomplete capture of the now contaminate-rich plume would explain why the concentrations increased down-gradient, outside the radius of influence of the DDC well system.

Nonetheless, this demonstration clearly shows the benefit of the vertical flow component created by GCW systems in effecting non-aqueous phase liquids (NAPL) or sorbed materials. However, if no highly contaminated source zones with sorbed materials exists, then there appears no value inducing vertical flow as with GCWs. Additionally, most GCW systems utilize co-current flow to strip volatiles from groundwater. Co-current air strippers like those in GCW systems require much higher airflow to water ratios than counter-current strippers to achieve the same level of performance. Therefore, in the absence of deep aquifers, greater improvements in process treatment efficiency may be obtained with improved aboveground treatment. The reader should also realize that based on a simple mass balance, if a given volume of groundwater is captured by a well, and the pumping rate remains constant so that some of the partially-treated water begins to recirculate, the volume of untreated groundwater that can be captured is reduced (Parsons Engineering Science 1997).

The importance of proper and adequate monitoring is also evident from this

demonstration and cannot be overstated. As pointed out earlier, after completion of the pilot tests in May 1995, the DDC system remained in operation unattended and continued to operate for an unknown period of time before stopping due to blower failure. This obviously changed the contaminant conditions around the single pilot DDC well from conditions outside its' area of influence. Subsequently, when the large-scale DDC system began operating, the influent concentration around SWD showed no mass entering the pilot DDC well. Consequently, without the installation of new influent and effluent monitoring points with the new DDC wells, the consultant was forced to estimate the influent conditions. This involved "assuming" groundwater circulation was occurring and the concentration of dissolved hydrocarbons in the inflow of all DDC wells was equal to the average TPH concentration in three on-site monitoring points (SWD, PE3-S, and MW11). Unfortunately, the appropriateness of this assumption is left to the reader.

Furthermore, a mass balance comparison of the SVE system effluent of 3,449 pounds of TPH versus the estimated 15,767 pounds of TPH removed from in-well stripping of groundwater represents a one order difference in magnitude. Consider the following boundary conditions: The mass removed from the site equals the mass seen at the SVE effluent, plus any biodegradation occurring in soil or groundwater (and any contaminant which migrated down gradient not captured by the DDC well). Moreover, the mass seen at the SVE effluent has three components: 1) mass removed by direct volatilization of soil contaminants, 2) mass removed by bioremediation, and 3) mass removed from groundwater by in-well stripping which ultimately entered the vadose zone through the upper screen. Consequently, if 15,767 pounds of TPH were removed from the groundwater during the demonstration, the mass seen at the SVE effluent should have approached 19,216 pounds of TPH during the 533 days of operation. This estimate is based on the sum of the mass removed by direct soil volatilization, mass removed via biodegradation occurring in the soils, and the mass removed by groundwater stripping which entered the vadose zone, and was subject to the SVE influence.

Finally, the effects of groundwater fluctuation during this demonstration must be mentioned. According to Table 1, 1,286 pounds of TPH removed via volatilization during the period 25 Nov 96 to 15 Jan 97 and represents 40 percent of the total mass volatilized during this study. Interestingly, however, the period 25 Nov 96 through 15 Jan 97 also represents approximately only 10 percent of the total operational time. Increases in stripping efficiencies and influent concentrations can not account for this increase. Stripping efficiency of the DDC wells during this period averaged 80.5 percent compared to the overall average of 79.5. Figure 4 shows the average on-site concentration during this period was below initial concentrations. Rather this period of increased volatilization corresponds to the period of greatest fluctuation in groundwater elevation and a drop of approximately 1.4 feet according to Table 2. Therefore, the impact of the SVE system on the total mass removed appears to be substantial to say the least.

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# **Volatile Organic Compound Offgas Treatment Technology Demonstration and Comparison**

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## **Executive Summary**

The success of this project has been instrumental in merging the requirements of the Navy's Installation Restoration (IR) cleanup program with the innovative technology demonstration capabilities of the Research and Development (R&D) program. There were three major elements of this project's success. The first element was the demonstration/validation of an innovative ultra violet (UV) oxidation technology to treat volatile organic compound (VOC) offgas from an operating soil vapor extraction (SVE) system at IR Site 9 at Naval Air Station (NAS) North Island, San Diego CA. The second element was the development of a searchable database containing comparisons of all available VOC offgas treatment technologies, which other project managers can use to help select the best available technology for their needs. The final element was development of a process to link the IR cleanup needs with the R&D funding and technical expertise to provide better solutions for the Navy's remediation program.

## **Project History**

The Navy established the Alternative Restoration Technology Team (ARTT) in 1996, to identify barriers to implementing innovative technologies and recommend solutions for Remedial Project Managers (RPMs). A presentation was made at the January 1997 ARTT meeting regarding the planned R&D efforts for the fiscal year (FY) 1998 through FY 2000. The ARTT members voiced concerns over an apparent disconnect between the current IR needs and the proposed R&D projects. After reviewing the R&D program, the ARTT recommended a process change to better integrate these two programs. The three successful elements of this project are described below.

The first step in this process was to successfully demonstrate a single project. A proposal was developed, submitted, and approved to perform a technology



demonstration project at NAS North Island, which is the Navy Environmental Leadership (NELP) base on the west coast. There was already an ongoing SVE project at IR Site 9, which was using carbon adsorption with on-site steam regeneration of the carbon beds as the VOC offgas treatment technology. There was also a NELP project underway at IR Site 9 to demonstrate an in-well stripping technology using flameless thermal oxidation as the VOC offgas treatment technology. The R&D proposal recommended testing another technology, UV oxidation, on a slip-stream of the SVE air stream to achieve a direct comparison of three innovative treatment technologies. The details of this demonstration are described in the UV Oxidation Technology Demonstration section below.

The project team wanted this project to be more than one of many technology demonstrations which simply prepare a final voluminous report which most RPMs do not have time to read. Rather, this team wanted to go beyond that and produce a usable tool for RPMs regarding remedy selection. There is a need for easy-to-use technology summaries and comparisons when making these technology selections. Therefore, the second element of this project involved a detailed literature search of all available VOC offgas treatment technologies, a normalization of the data based on technology development status, and development of a searchable database to serve as a tool to project managers for technology selection. The details of this database are described in the VOC Offgas Treatment Technology Database section below.

The final element of this project was the development of an improved process to better integrate the IR program needs with the R&D program capabilities. The team demonstrating the initial UV oxidation project began showing success so quickly that the decision was made to immediately implement the new process. A request for additional projects was sent out in August 1997, and 15 new project proposals were received. These projects were reviewed by an ARTT subcommittee, which selected two projects for implementation. The two projects were funded in FY 1998 and are underway. Another request for proposals was sent out in August 1998. At this time, 19 proposals have been received and are being evaluated by the ARTT subcommittee. The details of this process are described in the IR and R&D Integration section below.

## **UV Oxidation Technology Demonstration**

Following the January 1997 ARTT meeting, many discussions were held between the R&D program managers and the ARTT members on ways to demonstrate one successful project integrating an IR program need with a R&D solution. NAS North Island had been operating an SVE system at IR Site 9 using carbon adsorption with on-site steam regeneration as the VOC offgas treatment technology. The system was designed to be 99% efficient with a maximum design inlet of 2,500 parts per million (ppm) total VOCs at 3,000 standard cubic feet per minute (scfm). While this 99% removal efficiency sounds good, this equates to a maximum possible emission of six tons of VOCs per year, which greatly concerned the Coronado community. The community wanted a treatment system approaching 100% efficient. That was the IR program need. A proposal was submitted to the R&D program managers to demonstrate the Process Technology, Inc. (PTI) UV oxidation system on a slip-stream of the Site 9 VOC offgas to determine if it would be a more efficient means of treating this offgas. Since this project showed a good match of need and capability, the R&D program managers approved the project in April 1997.

The project implementation team was formed with representatives from Naval Facilities Engineering Command, Southwest Division (SWDIV) and the Naval

Facilities Engineering Service Center (NFESC). It was agreed that the SWDIV RPM would lead the project and that the NFESC team members would provide technical expertise for technology evaluations and contracting support. The team looked into all means possible to fast track this project.

The first step in the demonstration project was to get regulatory buy in for this demonstration project. This went very smoothly. The RPM spoke with the California Department of Toxic Substances Control (DTSC) about this proposal. The current SVE treatment at NAS North Island was operating under an approved action memorandum (AM) and remedial action plan (RAP). This proposed demonstration would take a slip-stream of the VOC offgas from the SVE system, treat it, and then discharge it back to the inlet of the carbon adsorption system. The DTSC representative approved the demonstration stating that this configuration would not be generating any new waste streams and was consistent with the AM and RAP.

With regulatory approval, the team set to work contracting with PTI. NFESC had established a Broad Agency Announcement (BAA) process where a technology vendor submits an abstract. The abstracts are reviewed semi-annually by a team of engineers and scientists. Approved abstracts are placed into books of abstracts which can now be found on the DENIX web page at <http://www.denix.osd.mil>. Once a technology is approved, it may be contracted for a demonstration project meeting all of the Federal Acquisition Regulation requirements. At the time of this project, PTI was an approved vendor. This considerably reduced the time required to acquire a contract. The PTI contract was awarded in June 1997.

Beyond the innovative use of the BAA for contracting, the team also wanted to reduce the government's risk regarding the success on this project. In many technology demonstrations, all of the risk of the success of the project lies with the government based on the type of contracting. Whether a cost-plus or fixed price contract vehicle is used, there is very little risk or incentive on the contractor's part. Therefore, the team opted for a combined fixed price and fixed unit price contract. The government agreed to pay for all mobilization, demobilization, workplan, report, and sampling requirements on a fixed price basis. All of the fieldwork was based on a negotiated fixed unit price basis. The government monitored the mass of contaminants treated by PTI and agreed to pay PTI for the amount of mass destroyed. A flame-ionized detector (FID) was used to monitor the influent and effluent concentrations of the offgas air stream. Using the flow rate, a mass destruction was calculated. PTI was paid only for the mass their system was able to destroy.

Following contract award, PTI immediately began writing the workplan. The team held over-the-shoulder review meetings with PTI to shorten the workplan preparation time. This saved approximately three months of the project duration. The workplan was approved in September 1997.

PTI mobilized to the site from October 7 through 11, 1997, and began system start up from October 12 through 18, 1997. The first phase of operation involved parametric testing of several PTI system configurations to determine the most efficient mode of operation for the contaminants at Site 9. These contaminants consisted of a mixture of chlorinated and non-chlorinated VOCs. The major contaminants of concern were tetrachloroethene (PCE), trichloroethene (TCE), cis-1,2-dichloroethene (1,2-DCE), octane, and toluene. Following the parametric testing phase, steady-state testing was performed on the optimal system configuration. The goals of the PTI demonstration were:

- Determine the total average destruction and removal efficiency (DRE)

achieved by the PTI system for all VOCs measured in the SVE offgas, as well as individual DREs for critical VOCs.

- Develop treatment cost data for a 3,000 scfm PTI system, designed to meet the DREs measured above, for VOC-contaminated soil vapor similar to those at Site 9.
- Characterize and quantify secondary waste streams generated by the PTI system at Site 9 and determine the appropriate disposal option(s) for each. Estimate the costs of disposal of all secondary waste streams generated.
- Characterize and quantify all residuals, including hydrochloric acid, chlorine, phosgene, carbon monoxide, and dioxins exiting the PTI system.
- Document observed operating problems and their solutions.
- Disseminate the results of the demonstration throughout the Department of Defense (DoD), the Department of Energy (DOE), private industry, state regulatory agencies, and the NAS North Island Restoration Advisory Board (RAB).

The parametric testing found that the optimum system configuration consisted of a fluidized bed concentration unit and a photolytic destruction unit (PDU). The concentration unit produced a low flow, high concentration VOC vapor that was treated in the PDU. The concentration unit pre-concentrated organics up to 1,000 times with a corresponding decrease in scfm flow rate. PTI completed the steady state testing on February 6, 1998 and demobilized from the site from February 7 through 12, 1998. The data was compiled into a technology evaluation report, which was completed in May 1998. This entire report can be viewed and downloaded from the NFESC home page at <http://www.nfesc.navy.mil>. Following is a summary of the demonstration results:

- The PTI system, configured as a combined concentration unit and PDU, was installed and commissioned within one week. The equipment operated 24-hours per day, seven days per week. The PTI system achieved an on-line (operational) availability rating of 89%.
- The concentration unit reduced the SVE offgas of approximately 270 scfm to less than 2 scfm, prior to treatment in the PDU.
- The PTI system was successful at removing VOCs in the SVE offgas to below the maximum allowable emission at Site 9 of 25 parts per million by volume (ppmv). During steady-state operations, the PTI system achieved an average total VOC DRE of 95.44%.
- The estimated unit cost of implementing a 3,000 scfm PTI system at Site 9 is \$3.77 per pound of VOC treated.
- The fixed unit price contracting mechanism saved \$60,000 in the demonstration project. The contract was awarded with a limitation of cost of \$150,000. Based on the calculated mass treated by the PTI system, a contract deductive modification of \$60,000 was awarded in April 1998, allowing these funds to be used on another project.

These results demonstrate that the PTI technology is a viable treatment option for VOC offgas treatment. This information has been incorporated into the VOC Offgas Treatment Technology Database to allow project managers to compare the

benefits of this technology with all other available technologies.

## **VOC Offgas Treatment Technology Database**

While the results of the PTI demonstration discussed above clearly demonstrate a success, the team chose to go a step further. The technology demonstration report as a stand alone document is only moderately useful to an extremely busy project manager looking for a VOC offgas treatment technology. A project manager would need to read this report and several other similar reports in order to choose the most appropriate technology for any given application. Therefore, the team decided to perform all of this data gathering and document the results into a searchable database to serve as a tool for project managers to use.

The NFESC engineers performed a comprehensive literature search to find all of the available, proven VOC offgas treatment technologies. The information gathered consisted of varying degrees of cost and performance data. This data required a means of normalization so the technologies could be effectively compared. The NFESC engineers performed this grueling task. Once all of the data was normalized to an even point, comparison tables were developed for these technologies. NFESC then contracted Battelle to develop a searchable database as a project manager's tool. This was completed in July 1998. The database is currently available as a desktop CD-ROM and is also downloadable from the NFSCE home page at <http://www.nfesc.navy.mil>. Following is a description of the database, as it will appear in the fall 1998 NFESC RPM newsletter:

### **Database Structure**

The database is structured in the hierarchy of treatment technologies, then by individual commercial systems of the respective technologies. Based upon a literature search conducted by NFESC, there are seven technologies that could be applicable to VOC off-gas treatment. These are:

- Alkali Bed Reactor
- Catalytic Thermal Oxidation
- Flameless Thermal Oxidation
- Plasma Destruction
- Thermal Oxidation
- UV Oxidation
- Vapor Phase Adsorption

### **Technology/System Profile**

Each technology and specific system configuration is fully described in a profile and illustrated by a schematic diagram. The pros and cons of each technology are provided in an easy-to-read tabular format, and performance and cost data are displayed on screen as the user scrolls through the available technologies. Information provided for each system configuration includes:

- Destruction removal efficiency
- Unit cost range
- Inlet concentration limit
- System flow capacity
- Subcomponents
- Number of units installed

- Secondary hazardous waste generated
- Vendor and point of contact

### **Unit Cost Estimator**

The database has a built-in *Unit Cost Estimator* for calculating unit treatment cost in dollars per pound of VOC treated. This approach allows the user to better assess the relative cost effectiveness of each treatment option. The cost estimator also allows the user to estimate a site-specific application of any of the database technologies by customizing various parameters.

### **Query/Report Wizard**

The heart of the database is the query and report generation module that allows the user to define which database fields to query and which fields to report. The feature was purposely modeled after the NORM query/report wizard to take advantage of a query routine already familiar to the targeted user—the RPM. This feature can be used to prepare user defined tables or lists for the purpose of comparing technologies or their subsystems against one another.

### **Technology Screening/Evaluation Tools**

The NFESC made it easier to compare the strengths and weaknesses of the treatment technologies by providing two kinds of graphics-based screening tools. One is a "Consumer Reports"-like *Screening Matrix* offered from the main screen menu bar. The *Screening Matrix* displays each treatment technology and its associated commercial configurations and rates them according to thirteen different criteria. The screening criteria are:

- Development status
- Availability
- Contaminants treated
- Destruction removal efficiency
- Hazardous waste generated
- Footprint size
- On-site utilities
- Size threshold
- Scale up/down
- Regulatory acceptance
- Community acceptance
- Cost
- Capital or O&M intensive

The second technology evaluation tool features a runtime version of *Expert Choice™ Pro 9.0*. *Expert Choice™* is a system for the analysis, synthesis, and justification of complex decisions and evaluations. Based on the Analytical Hierarchy Process, this tool allows a decision-maker to compare tangible factors with intangible factors. Sensitivity analysis can be performed in five different ways (all graphical) to determine how changes made to one or more judgements affect the final priorities. The NFESC modeled the VOC off-gas treatment technologies into the *Expert*

*Choice<sup>TM</sup>* application to assist with the evaluation and comparisons of the database technologies.

## Help

Plenty of online **Help** is available to assist the users. Help includes a complete glossary of all terms used within the database, details of the cost model used for the **Unit Cost Estimator**, and provides all major cost and performance assumptions used in formulating the data.

A snap shot of the database main screen is shown in Attachment (1). A procedure to interpret the snap shot screen is given in Attachment (2), which shows step-by-step description and explanation of all the features of the screen.

## Benefits

The database provides an effective tool for RPMs to search available VOC off-gas treatment technologies, including emerging, innovative, and conventional technologies. It allows the user to compare and select technologies that meet site-specific conditions by letting the user make tradeoffs on different parameters in order to determine the optimum technology/system. The easily accessible, normalized data along with the graphical evaluation tools provided by the database will not only save time required to research the technologies, but will assist RPMs in selecting optimum technologies that are better, cheaper, and faster.

## Future Plans

The database is currently available on CD-ROM and can be downloaded from the NFESC web page, at <http://www.nfesc.navy.mil>. Future efforts include the development of an interactive Internet version that can be executed on-line through the NFESC web page. The database will be updated by expanding upon cost and performance fields and to incorporate other technologies, as they become available. The Internet version of the database is expected to be available by December 1998. The database will be maintained by NFESC and updated semi-annually.

## IR and R&D Integration

The R&D managers realized the success of the first two aspects of this project immediately. Therefore, they decided to immediately implement the revised process for integrating IR cleanup needs with R&D capabilities. It was decided that two additional projects would be awarded in FY 1998. Each project would receive up to \$250,000 for implementation. A request for project proposals was sent to all of the Engineering Field Divisions and Activities (EFD/As) in August 1997. A total of 15 proposals were received from the various EFD/As. A R&D review sub-committee was set up with ARTT members and NFESC technical experts. These projects were screened and two were chosen for implementation. The first project involves the collection of toxicity data for ordnance compounds in sediments to propose cleanup criteria to the regulatory agencies. The point of

contact for this project is Steve Saepoff. The second project involves the injection of Fenton's Reagent (catalytic hydrogen peroxide) as source reduction for a VOC contaminated aquifer. The point of contact for this project is Mike Maughon. Both of these projects are underway. RPM contact information is listed on the next page if further information is desired on the status of these two projects (<http://www.denix.osd.mil/denix/DOD/Working/ARTT/artt.html>: **DENIX account required**).

Although there were 13 projects not chosen for R&D funding, the proposing RPMs were not left to fend for themselves. By submitting a R&D proposal, these RPMs received exposure of their needs to the NFESC engineers and scientists who assisted the RPMs with other leveraged funding programs and alternative solutions. The R&D program managers have also used this data to update the Navy's Environmental Quality Requirements. The NFESC has taken the lead in writing the Navy's needs based on output from the NORM database. This was reviewed by the R&D sub-committee for accuracy. The R&D sub-committee is using this needs analysis to focus the review of the FY 1999 funded projects.

The on-going effort includes another request for R&D proposals, which was sent out to all of the EFD/As in August 1998. This year, 18 proposals were received. These proposals are currently under review by the R&D sub-committee. With the continued success of the past two years, the R&D managers are planning to award three projects in FY 1999. Selection of these projects should be complete by the end of October 1998.

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# **Application of In Situ Thermal Desorption (ISTD) to Remediate Polychlorinated Biphenyls (PCBs) from Soil**

## **1.0 Introduction**

This report describes the successful demonstration of In Situ Thermal Desorption (ISTD) technology using Thermal Blankets and Thermal Wells at the former Mare Island Naval Shipyard, Vallejo, CA. The demonstrations were conducted from September through November 1997 by TerraTherm Environmental Services and RT Environmental Services, in cooperation with the U.S. Navy and the Bay Area Defense Conversion Action Team (BADCAT) Environmental Technology Project (ETP).

ISTD technology uses the direct application of heat supplied by electrical heater elements to raise the temperature of soils in situ to the boiling point of the organic contaminants targeted for removal. Heat is applied through the use of Thermal Wells (to heat soil radially outward from each well) or Thermal Blankets (to heat soils downward from the surface). Both forms of the technology were demonstrated on the Mare Island Installation Restoration Site 11 (IR11). Vapors created during heating were drawn through a flameless thermal oxidizer with vapor phase activated carbon polishing using a vacuum blower collection system.

Soils at the Thermal Well Demonstration area, adjacent to a former electrical shop, were impacted with Polychlorinated Biphenyls (PCBs) identified as Aroclors 1254 and 1260 by USEPA Method 8081. Samples collected within the demonstration area during the Remedial Investigation exhibited a maximum concentration of 2,200 mg/kg. The Thermal Well demonstration was conducted using a network of 12 wells installed to a depth of 14 feet. After reaching the target soil treatment temperature of 600°F over a treatment period of 37 days, all post-treatment soil samples had no detectable PCB concentrations (less than 0.010 mg/kg).

Soils used in the Thermal Blanket Demonstration were impacted by the release of an oily sludge with a total PCB concentration of 24,000 mg/kg. The Thermal Blanket Demonstration was conducted using two adjacent 8 foot by 20 foot heating units, and treated soils to a depth of 12 inches over a period of 7 days. Post-treatment soil samples had no detectable PCB concentrations (less than 0.010 mg/kg).

## **1.1 Background Information**

The Bay Area Defense Conversion Action Team (BADCAT) Environmental Technology Project (BADCAT ETP) was created to evaluate emerging and innovative environmental technologies in expediting conversion of the 12 closing military bases in the San Francisco Bay Area to civilian uses.

The ISTD technology was selected for evaluation because it had been demonstrated to be an effective method for treatment of a wide range of problematic organic contaminants. ISTD had been recently used for treatment of soils contaminated with PCBs, pesticides, chlorinated solvents, and petroleum wastes including Polynuclear Aromatic Hydrocarbons (PAHs). In each thermal

application method, contaminant vapors were drawn through a vacuum collection system and destroyed/treated using a flameless thermal oxidizer with vapor phase activated carbon polishing. The air pollution control (APC) system was controlled and monitored using a programmable logic controller (PLC) and continuous emissions monitoring system (CEMS).

ISTD technology provides an innovative technology to replace incineration, landfill disposal, and/or soil venting. ISTD addressed the needs of the BADCAT ETP in the following ways:

- ISTD destroys the organic contaminants in situ and on site, while generating a minimum of residues for off-site disposal.
- ISTD works effectively and consistently in a wide range of soil types, and has been proven effective in removing organic contaminants from heavy clay soils where alternative in situ technologies are ineffective.
- ISTD has been demonstrated to be a safe technology by protecting on-site personnel and the public from exposure of contaminants during removal and destruction.

## **1.2 Demonstration Objectives**

The primary objective of the Field Treatability Demonstration was to evaluate the performance of In Situ Thermal Desorption technology for remediation of soils containing PCBs at the Mare Island Shipyard IR11 Site.

The objectives of the Demonstration included the following:

- Determination of the level of PCB reduction in site soils achievable by the In Situ Thermal Desorption Technology.
- Acquisition of data to evaluate the efficiency of the system and to obtain the cost data as may be applicable for bringing full scale ISTD technology to this and other sites.
- Demonstrate that the Thermal Wells can achieve reduction of PCB concentrations to less than 2 mg/kg when the initial PCB concentration is as high as 2200 mg/kg in the soil matrix at the site.
- Demonstrate that the Thermal Blankets can achieve reduction of PCB concentrations to less than 2 mg/kg at a depth of up to twelve (12) inches.

## **2.0 Site/Facility Description**

The demonstration site was located adjacent to the northwestern corner of the former Mare Island Electrical shop (Building 866). The area was paved, and contained PCB-contaminated soils in a previously disturbed excavation area. Deep contamination (up to 14 feet below surface grade) adjacent to the building represented a difficult location to implement other technologies including excavation.

### **2.1 Site History/Characteristics**

Building 866 is located between Cedar and Suisun Avenues and 11<sup>th</sup> and 12<sup>th</sup> Streets, near the center of former Mare Island Naval Shipyard, Vallejo CA. The

test site was located in the area of a former 3,000 gallon grease trap. The facility is on a relatively flat portion of a hillside with a surface elevation approximately 26 feet above mean sea level. The southwest half of the facility is located on bedrock, while approximately three to four feet of fill overlies the bedrock in the northeastern portion of the property.

Building 866 is a five story concrete block structure built on a concrete slab at grade. The area of the former grease trap, which was connected to the industrial wastewater (IW) collection system, is now paved. Underground utilities in the area of the site include storm water and sanitary sewer pipelines, dredge and saltwater pipelines, and a former fuel oil pipeline.

The facility was used as an electrical workshop from 1955 until 1994. Activities in the building included electrical and electronic equipment processing and overhaul. Materials used during the processing and overhaul activities included lubricants, sealants, paints, plating compounds, epoxies, rubber compounds, oils, photochemicals, solvents, degreasers, and detergents. Solvents (including methyl ethyl ketone, and stoddard solvent) were frequently used in most of the facility work areas from 1955 until the late 1960s.

From 1955 to 1978, transformers washed in the cleaning room contained PCB oils. Transformer washing procedures included draining the oil and pressure washing the interior of the transformers with steam and degreasing solvents or detergents. The liquid waste and sludge that accumulated in the cleaning room sump were pumped through a 6-inch diameter drain pipeline into the grease trap near the western corner of the building. In 1981, the Navy cleaned and plugged the floor drains in the cleaning room. The sludge was found to contain PCBs, and further samples revealed PCB contamination in the cleaning room sump, and the grease trap collection system. As a result, these systems were cleaned and removed from service. The grease trap was subsequently removed, and the lines were capped.

Prior to the demonstration activities, forty-nine soil borings had been drilled and logged at the Mare Island electrical shop during the Remedial Investigation (RI) study. Borehole depths ranged from 8 feet to 34 feet below ground surface (bgs). Three geologic units were identified in the region of the test site. These included, from top to bottom stratigraphically, (1) artificial fill material, (2) silt clay, and (3) weathered bedrock. Based on the geologic cross sections for the Mare Island electrical shop provided in the RI, the thermal wells were installed in a homogeneous weathered bedrock unit, consisting of weathered siltstone and fine-grained sandstone.

Groundwater in the uppermost aquifer beneath Building 866 is encountered approximately 9 feet to 15 feet bgs; groundwater elevations ranged between 10.5 to 17.69 feet above mean sea level. The direction of flow in the shallow water-bearing zone is to the east toward Mare Island Strait. A slug test performed in June 1997 on an existing well near the demonstration area indicated a preliminary hydraulic conductivity value of  $1 \times 10^{-5}$  cm/sec.

### **Thermal Well Demonstration Area Soils**

Organic compounds detected in soil at Building 866 included PCBs, volatile organic compounds (VOCs), phenol, TPH, and pesticides. Of the organic compounds detected, only PCBs were detected in concentrations exceeding applicable Preliminary Remedial Goals (PRGs).

Groundwater samples collected from locations near the grease trap excavation

contained low concentrations of chlorinated solvents (up to 6 micrograms per liter ( $\mu\text{g/L}$ )) and TPH (up to 300 milligrams per liter ( $\text{mg/L}$ )).

### **Thermal Blanket Demonstration Soils**

During the drilling of the thermal well field for the ISTD demonstration, a pipeline containing oily liquid was encountered. This pipeline was believed to be a portion of the drain system previously connecting Building 866 to the grease trap. Soils excavated from this area were used for the Thermal Blanket demonstration. Approximately 10 cubic yards of excavated PCB-impacted soil was staged at the Building 866 demonstration site. The asphalt pavement at the Thermal Blanket demonstration site was saw cut and removed from a 26 by 30 foot area. A shimstock liner was placed in the shallow excavation and filled. The demonstration soils were sampled after placement in the cell. The mean concentration of the four composite samples collected exceeded 20,000  $\mu\text{g/kg}$ .

## **3.0 Demonstration Procedure**

The procedure for the demonstration included three (3) phases; feedstock characterization and system installation, system operation and monitoring, and post treatment sampling and system de-mobilization.

Feedstock characterization involved the assessment of the demonstration area specific to implementation of the technology. Pre-operation samples were collected within the specific target treatment area for direct comparison to post-treatment samples. Soil samples were analyzed for Total PCB concentrations using USEPA Method 8081. A summary of the results for the pre treatment samples is provided in Tables 1 and 2.

System installation required the development of temporary utilities and the installation of the Thermal Well field. The utility requirements for the demonstration included:

- Electric service transformer to provide 480V, 3 Phase, with a maximum capacity 500 kW was installed for the operation of the Thermal Wells, Thermal Blankets, and the APC system.
- Electric & telephone service to the control trailer, work trailer, and office trailer.
- Potable water; fire protection water supply.
- Sanitary sewer line for restrooms.

The twelve (12) thermal/vapor extraction wells were installed with a standard drill rig to a depth of fourteen (14) feet. Figure 1 presents the thermal well and thermocouple arrays. Removable stainless steel well casings with a screened interval from six (6) inches to fourteen (14) feet below ground surface (bgs) were installed. The heating elements were installed upon completion of casing installation activities. The entire treatment area was covered with a steel shimstock liner to provide a surface seal and to control fugitive emissions from near surface soils. The wells were sealed, piped via a manifold to the MU-125 treatment system, and connected to the power supply.

### **Figure 1 Thermal Well Field Layout**

Inconel sheathed K-Type thermocouples were installed on each of the wells to monitor the heating element temperature. Magnehelic pressure gauges were installed on the vacuum system piping to monitor wellhead vacuum pressures. For

the Thermal Well Demonstration, thermocouple arrays were installed at depths of 3', 6', 9', and 12' bgs in seven (7) locations at the midpoint between wells to monitor the rate of soil heating.

The MU-125 air pollution control (APC) system was equipped with a cyclone separator, flameless thermal oxidizer, heat exchanger, carbon vessels, and dual vacuum blowers. Figure 2 presents the MU 125 APC system. The MU-125 APC system trailer included an emergency generator and a control room containing a continuous emission monitoring (CEM) system and the Programmable Logic Controller (PLC) data acquisition system.

The process vapor stream was continuously monitored for the concentrations of CO<sub>2</sub>, CO, THC, and O<sub>2</sub>, using a calibrated Rosemount continuous emission monitoring system (CEMS). The CEMS utilized an extractive sample probe and conditioning system. The sample stream was introduced to a non-destructive infrared analyzer for the quantification of CO and CO<sub>2</sub> prior to the analysis of O<sub>2</sub> using a zirconium oxide detector and THC using a flame ionization detector (FID). CEM data was acquired electronically and displayed graphically.

The operation and monitoring of the ISTD process occurred in three (3) phases, startup, heat application and cool down during both demonstrations.

#### **Startup: Thermal Wells**

- The first phase of operation was ramp-up of process equipment temperatures. The thermal oxidation system was heated to the target operating temperature of 1600-1800°F for PCB destruction. Process equipment start-up required approximately 12 hours, and was completed on October 10, 1997.

#### **Heat Application: Thermal Wells**

- The Thermal Well heating elements were slowly energized over a period of approximately 6 hours. The final operating temperature of these heaters was between 1400°F and 1600°F.
- Contaminant destruction occurred during the heating phase when the heating elements were at full temperature and the soil around the wells was slowly increased to the target treatment temperature of 600°F. The heating phase was terminated when the thermocouples in the center triangle of the Thermal Well array reached the target temperature. The heating phase was conducted for a period of 35 days from October 11 to November 15, 1997. After achieving the target temperature of 600°F, the thermal wells were held at maximum power for a 48 hour period for a total heating time of 37 days.

#### **Cool down: Thermal Wells**

- The final phase of operation was the cool down. During this period, the heating elements were de-energized and soils were allowed to cool. Post treatment sampling was conducted on 2 December 1997 using a brass-lined GEOPROBE sampling tool and vibrating hammer.

#### **Startup: Thermal Blankets**

- The thermal oxidation system was maintained at the target operating temperature of 1600-1800°F while the process piping and thermal blankets

were accessed. The process piping connections were completed on November 17, 1997.

#### **Heat Application: Thermal Blankets**

- The Thermal Blanket heating elements were slowly energized over a period of approximately 6 hours. The final operating temperature of the elements was between 1400°F and 1600°F.
- Contaminant destruction occurred during the heating phase when the heating elements were at full temperature and the soil below the blankets was slowly increased to the target treatment temperature of 600°F. The heating phase was terminated when the thermocouples at the 12" depth below each Thermal Blanket reached the target temperature. The heating phase was conducted for a period of 6 days from November 17 through November 24, 1997. After achieving the target temperature of 600°F, the thermal blankets were held at maximum power for a 24 hour period for a total heating time of 7 days.

#### **Cool down: Thermal Blankets**

- Thermal Blankets were de-energized and soils were allowed to cool. Post treatment sampling was conducted on 3 December 1997 using stainless steel trowel sampling tools.

### **4.0 Performance Assessment**

Performance data collected and analyzed during the demonstrations consisted of three types of data. These data included:

- Soil sampling and analysis data used to determine whether the target treatment level of 2 mg/kg was achieved.
- Operational data, including soil and process temperatures, system vacuum readings, and total vapor flow rates.
- Emissions data used to ensure that the thermal oxidation system was operating within normal limits.

#### **4.1 Soil Data**

Soil samples were analyzed by a Cal EPA certified laboratory for PCBs using EPA Method 8081. There were no reported matrix problems and analytical quantitation limits of 10 µg/kg were achieved. Data validation, performed by an independent professional, confirmed the validity of the data.

Pre-treatment and post-treatment PCB test results for the Thermal Well demonstration are summarized on Table 1. All post-treatment samples had no detectable PCB concentrations at a quantitation limit of 10 µg/kg.

Pre-treatment and post-treatment PCB test results for the Thermal Blanket demonstration are summarized on Table 2. All post-treatment samples had no detectable PCB concentrations at a quantitation limit of 10 µg/kg.

#### **4.2 Operational Data**

Operational data collected and logged by the PLC data acquisition system include:

- Heater element temperatures at 3 elevations in 12 wells were to monitor performance and automatically control the heater power supplies.
- Soil temperatures at 3 elevations in 7 locations placed at the center of each set of three thermal wells were used to monitor the rate of heating.
- Process vapor temperatures within the pipe manifold and throughout the process, including 3 locations within the flameless thermal oxidizer, before and after the carbon vessels, and in the exhaust stack.
- Total process flow rate was monitored to confirm the continuous collection of process vapors from the ISTD system.

A composite graph of the Thermal Well demonstration soil temperatures is presented in Figure 3. The heating time required to achieve the boiling point of water at the center thermocouples ranged from approximately 3 to 5 days. The soil temperature remained at this level until the soil was dried. The soil temperatures exceeded 212°F from approximately 6 to 15 days from the start of the heating cycle. The soil temperature rose at a rate of approximately 1.25°F per hour until the target temperature of 600°F was reached. The heating time required for each center thermocouple array to reach the target treatment temperature ranged from 31 to 37 days. At shutdown of the Thermal Well heaters, soil temperatures ranged from 600°F to 810°F at the thermocouple arrays placed at the centroids of the thermal well pattern.

An example graph of the Thermal Blanket demonstration soil temperatures is presented in Figures 4. The treatment time to remove the soil pore water was approximately 70 hours for Thermal Blanket #1 and 84 hours for Thermal Blanket #2. The cumulative time to reach the target temperature of 600° F was 160 to 165 hours.

Process flow rates ranged from a minimum of 38 to a maximum of 82 standard cubic feet per foot (scfm). Process vapor flow rate was maintained at above 65 SCFM to accommodate steam generation during the initial heating of soil. After the removal of the soil pore water, the process flow rate was reduced while maintaining a negative pressure within the process piping.

The flameless thermal oxidizer was monitored using Inconel sheathed K-Type thermocouples placed within the ceramic reaction bed matrix. During the treatment of extracted soil vapors during the demonstrations, the reaction bed temperature was in excess of 1800° F.

### **4.3 Emissions Data**

Emissions data collected and logged by the PLC data acquisition system included:

- Stack CO concentration (ppmv, dry basis)
- Stack CO<sub>2</sub> concentration (ppmv, dry basis)
- Stack THC concentration (ppmv, dry basis)
- Stack O<sub>2</sub> concentration (ppmv, dry basis)
- Stack O<sub>2</sub> concentration (ppmv, wet basis)
- Exhaust temperature

Carbon monoxide (CO) emissions were recorded continuously by the CEM system. Emissions were recorded below 10 ppmV with a 3 minute lag throughout

the demonstrations. The mean concentration was approximately 2 ppmV. Total hydrocarbon (THC) emissions were recorded using a flame ionization detector calibrated to methane (CH<sub>4</sub>). THC readings observed during the demonstrations ranged from 0 to 8 ppmV.

Carbon dioxide (CO<sub>2</sub>) emissions were recorded continuously by the CEM system and were observed at less than 2.0% throughout the demonstrations. The concentration was generally higher during the initial heating of the soil with a gradual decrease as the target treatment temperature (600°F) was achieved. Figure 5 presents the CO (ppmV), THC (ppmV), and CO<sub>2</sub> (%) observed throughout the demonstrations.

Excess oxygen as indicated by the percent of oxygen in the system emission measured on a wet basis was at or above 12% throughout the demonstrations with one exception. During the shutdown of the Thermal Well system and change over to the Thermal Blanket demonstration, the wet oxygen measurements ranged from a low of 10% to approximately 14%. Figure 6 presents the Percent Oxygen observed throughout the demonstrations.

Exhaust temperature was monitored by a thermocouple placed in the CEM sample port and recorded by the MU-125 data acquisition system. The temperature was maintained at approximately 200°F through adjustment of the heat exchanger flow. The scrubber beds were maintained at >220°F to minimize the formation of condensation within the vessels.

Stack exhaust samples were collected and analyzed using colorimetric indicator tubes on a daily basis to monitor emissions of hydrochloric acid (HCl). Stack samples collected throughout the demonstrations were observed to be less than 1.0 parts per million by volume (ppmV).

Process vapor samples were also collected from a sampling port located prior to the first scrubber bed which contained Sorbalit® HCl reduction media. HCl concentrations ranged from non-detect to 8 ppmv.

## **5.0 Cost Assessment**

### **5.1 Cost Performance**

One aspect of determining the overall performance of any technology is to verify that it can be implemented within a cost range that is known and predictable, and that is competitive with conventional and alternate technologies. It is also important to have an understanding of the cost structure for implementation of a technology, so that the effects of project-specific cost factors of the technology can be determined.

Experience with the implementation of ISTD at the BADCAT Demonstration, as well as prior ISTD demonstrations and remedial projects has established an overall cost range of approximately \$50 to \$250 per ton, depending on a number of site-specific factors. These typical costs are based on a per ton cost for simplicity of the end user, as is common for comparison disposal cost options.

Example construction and operating costs for implementation of ISTD remediation on a typical 1,000, 5,000, and 10,000 ton Thermal Well project are provided in Figure 7. As illustrated in these examples, larger projects tend to have treatment costs closer to the lower end of the cost range. Since the treatment time is a direct



function of thermal well spacing, primary cost savings are realized from the fixed labor cost during thermal treatment. Variable costs include cost of installation, mobilization & de-mobilization, process equipment, and electric power. Projects with simpler logistics or contaminants with lower boiling points will likely provide lower labor and energy costs due to shorter treatment times to achieve target treatment temperatures "in situ".

## **5.2 Cost Comparisons to Conventional & Alternative Technologies**

ISTD technology competes with a number of different technologies, depending on the type of project.

**Excavation and Off-Site Disposal**—Excavation and off-site disposal is an option for which cost is generally known, but has a high potential for significant cost growth. Total project costs can vary significantly, depending on the contaminant of concern. The cost of implementation of ISTD is generally more stable across a range of contaminants. ISTD is therefore highly competitive where difficult contaminants such as pesticides, PCBs, and dioxins, which have limited and expensive off-site disposal options, are involved.

The potential user of the ISTD treatment technology should carefully evaluate the total cost of off-site disposal, including transportation, taxes, excavation/loading, backfill and compaction, when comparing the cost of excavation and off-site disposal to ISTD.

**Excavation and On-Site Ex-Situ Treatment**—Ex-situ thermal treatment is frequently a lower cost solution than off-site disposal for very large projects. Due to the costs associated with project mobilization, ex-situ treatment is not generally effective for smaller projects. Also, costs can vary significantly depending on whether the unit is permitted for PCB destruction or is used only for conventional contaminants. ISTD is generally competitive in price with ex-situ methods, and has distinct technical, environmental and cost advantages where deep or difficult excavations are required.

**Other In-Situ Treatment Methods**—Soil vapor extraction is a technology which may compete with ISTD for removal of volatile organic contaminants. Soil vapor extraction will have lower capital and operating costs if soil conditions are favorable. However, where soil conditions are unfavorable, such as heavy clay soils, or less volatile contaminants, SVE may be technically impracticable.

**Other In-Situ Thermal Methods**—In-situ vitrification (ISV), dynamic underground stripping (DUS), radio frequency (RF) heating, and direct electrical resistive heating are thermal treatment alternatives for remediation of organic contaminants "in-situ". Due to the use of soil pore water as the medium for thermal energy transport, electric resistant and RF heating can only be effective at temperatures below 212°F. In addition, soil pore moisture must be maintained to enable continuous heating of the soil. Dynamic underground stripping requires the positive displacement of contaminants through the active injection of high pressure steam into the subsurface. Due to the high energy costs associated with the steam generation, DUS does not provide a cost advantage over ISTD. Furthermore, since steam is injected under positive pressure to the sub-surface, a high potential for migration of fugitive emissions from the treatment zone exists. In-Situ vitrification (ISV) utilizes a larger quantity of electrical energy while using an equivalent amount of sub-surface and vapor treatment systems as the ISTD technology. Thus, the costs for ISV is generally higher for the treatment of organic contaminants

"in-situ".

## 6.0 Acknowledgments

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